Production of multiply charged ions from the 4d photoionization of Cs$^+$

Tetsuo Koizumi, Takao M. Kojima*, Mutsumi Sano**, Naoki Watanabe#

Department of Physics, Rikkyo University, Tokyo 171-8501, Japan
 (*)(*)The Institute of Physical and Chemical Research (RIKEN), Saitama 351-0198, Japan
 (**)(**)Japan Synchrotron Radiation Research Institute, Hyogo 679-5198, Japan
 (#)(#)Institute of Low Temperature Science, Hokkaido University, Hokkaido 060-0819, Japan

E-mail: koizumit@rikkyo.ac.jp

Abstract. Using an ion-photon merged-beam apparatus, photoion yield spectra of Cs$^{2+}$ and Cs$^{3+}$ from the 4d photoionization of Cs$^+$ have been measured as a function of photon energy in the range 80-140 eV. Above 90 eV, the 4d giant resonance peak is observed clearly for Cs$^{3+}$ spectrum. Below 90 eV, some prominent discrete peaks are observed for both Cs$^{2+}$ and Cs$^{3+}$. These discrete peaks can be attributed to the 4d–np and 4d-nf transitions.

1. Introduction

The photoabsorption spectra of heavy atoms, such as Xe, Cs, Ba and the following lanthanides, show broad peaks called giant resonance in the 4d photoionization energy region. There has been great interest in systematic studies of 4d photoabsorption of atoms with increasing ionization along with isoelectronic sequence because these phenomena are good examples of the appearance of many-electron effects in atoms. However, very little is known experimentally on photoabsorption for ionic species. We have reported the photoion spectra of Xe$q^+$($q$=1-3)[1-4], Ba$^+$[5], and Eu$^+$[6,7] in the 4d photoabsorption region. In this paper, we present the relative photoion yield spectra of Cs$^{2+}$ and Cs$^{3+}$ from a Cs$^+$ target within the 4d giant resonance region with an ion-photon merged-beam technique. The 4d photoabsorption behavior of Cs$^+$ should be intermediate between Xe and Ba$^{2+}$. As mentioned above, only few experimental data have been published for Cs$^+$. The 4d photoabsorption spectrum of Cs$^+$ has been measured by Cummings and O’Sullivan[8] with a dual-laser-produced plasma (DLP) technique. However, because of absorption saturation the shape of the 4d giant resonance could not be deduced in their experiment.

2. Experimental

The ion-photon merged-beam apparatus used in this experiment has been presented by Koizumi et al. [5]. Briefly, the measurements were done using synchrotron radiation from the 2.5 GeV storage ring of the Photon Factory at the High Energy Accelerator Research Organization (KEK) at an undulator beam line (BL-16B). Photons were monochromatized by a 24m spherical grating monochromator.
Photon intensity was measured as electric current by a photodiode located at the end of the chamber. Target ions, Cs⁺, were produced by a surface ionization ion source, and extracted with 2 kV acceleration. The ions were deflected 90° by an electrostatic quadrupole and merged into the photon beam. After passing a 15 cm reaction region, the ions were demerged from the photon beam and charge analyzed by an electrostatic parallel plate analyzer. Primary ion current was monitored by a Faraday cup installed in the analyzer. The multiply-charged ions produced in the reaction region were detected by channel-type secondary electron multipliers combined with ion-to-electron converter plate in ion count mode. The vacuum pressure of the experimental chamber was kept lower than 4x10⁻⁸ Pa during the measurement. Photon energy of the monochromator has been calibrated by some photoabsorption lines. The accuracy of the energy scale in the present measurement was estimated to be better than 0.05 eV.

Relative photoion yield spectra of Cs²⁺ and Cs³⁺ from the 4d photoionization of Cs⁺ are presented in this paper as a function of photon energy in the range 80-140 eV.

2. Results and Discussion

Figure 1 shows the relative photoion yield spectra of Cs²⁺ and Cs³⁺ from the 4d photoionization of Cs⁺ as a function of photon energy. The energy resolution, E/ΔE, is about 400 in this measurement. The “total ion” in the figure 1. a) means the sum of Cs²⁺ and Cs³⁺ yields. Because the ionization after photoabsorption is dominant process, and the triple-ionization process is negligibly small in this energy region, the total ion spectrum obtained in this experiment corresponds to the photoabsorption spectrum.

The 4d giant resonance peak, which is attributed to the 4d→5f transition, is observed clearly for Cs³⁺ spectrum. It is worth noting that some window type resonances appear around at 100eV. Below 90 eV, some prominent discrete peaks are observed. There has been great interest in systematic studies of 4d photo-absorption of atoms along with isoelectronic sequence, Xe, Cs⁺, and Ba²⁺. For neutral Xe target, discrete peaks are not so prominent below 4d threshold [9]. On the contrary, for Ba²⁺, Lucatorto et al. [10] showed that drastic change happens, and many very prominent discrete peaks appear in lower energy region of the 4d giant resonance peak. The Cs⁺ case is intermediate between Xe and Ba²⁺.

Sato et al. [11] calculated the giant resonances of Xe-like isoelectronic sequence by the time dependent local spin density approximation (TDLSDA). The agreement between their calculation spectrum and the present total ion one is fairly good.

Figure 2 shows photoion yield spectra of Cs²⁺ and Cs³⁺ with higher energy resolution (E/ΔE≈800). Cummings and O’Sullivan [8] observed these discrete lines. The agreement between their result
and present one is very good. They showed that these transitions are attributed to the 4d–np and 4d-nf transitions by Multiconfiguration Hartree-Fock (MCHF) calculations. Vertical lines in the figure 2. a) indicate their calculated transition energies. \( d_{3/2} \) and \( d_{5/2} \) represent the 4d hole states. MCHF calculations reproduce our experimental data fairly well.

Fig. 2. Photoion yield spectra from Cs⁺ ions with higher energy resolution of \( E/\Delta E \approx 800 \) as a function of photon energy. a) Sum of Cs²⁺ and Cs³⁺ yield, vertical lines indicate the calculated 4d–np and 4d-nf transition energies [8], b) Cs²⁺ yield, c) Cs³⁺ yield.

### Acknowledgement
This experiment was done under approval of the Photon Factory of High Energy Accelerator Research Organization.

### References

[1] M. Sano, Y. Itoh, T. Koizumi, T. M. Kojima, S. D. Kravis, M. Oura, T. Sekioka, N. Watanabe, Y. Awaya, and F. Koike; J. Phys B: At. Mol. Opt. Phys. 29 (1996) 5305-5313.

[2] T. Koizumi, Y. Awaya, A. Fujino, Y. Itoh, M. Kitajima, T. M. Kojima, M. Oura, M. Sano, T.
Sekioka, N. Watanabe, and F. Koike; Physica Scripta. T73 (1997) 131-132.

[3] N. Watanabe, Y. Awaya, A. Fujino, Y. Itoh, M. Kitajima, T.M. Kojima, M. Oura, R. Okuma, M. Sano, T. Sekioka, and T. Koizumi; J. Phys B:At. Mol. Opt. Phys. 31 (1998) 4137-4141.

[4] Y. Itoh, A. Ito, M. Kitajima, T. Koizumi, T. M. Kojima, H. Sakai, M. Sano, and N. Watanabe; J. Phys B:At. Mol. Opt. Phys. 34 (2001) 3493-3499.

[5] T. Koizumi, Y. Itoh, M. Sano, M. Kimura, T. M. Kojima, S. Kravis, A. Matsumoto, M. Oura, T. Sekioka, and Y. Awaya; J. Phys B:At. Mol. Opt. Phys. 28 (1995) 609-616.

[6] T. M. Kojima, M. Oura, Y. Itoh, T. Koizumi, M. Sano, T. Sekioka, N. Watanabe, H. Yamaoka, and Y. Awaya; J. Phys B:At. Mol. Opt. Phys. 31 (1998) 1463-1468.

[7] T. M. Kojima, F. Chen, M. Kitajima, T. Koizumi, Y. Nakai, H. Yamaoka, and N. Watanabe; J. Electron Spectrosc. Relat. Phenom. 144-147 (2005) 71-74.

[8] A. Cummings and G. O’Sullivan, J. Phys. B30, (1997)5599-5607.

[9] See for example, J. B. West and J. Morton; At. Data Nucl. Data Tables 22 (1978) 103-107.

[10] T. B. Lucatorto, T. J. McIlrath, J. Suger, and S. M. Younger; Phys. Rev. Lett. 47 (1981) 1124-1128.

[11] M. Sano, X. M. Tong, and T. Watanabe; Physica Scripta. T92 (2001) 388-390.

and privert commucation.