Photoionization of Ions in the 4*d* Excitation Region

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1. Introduction

An 8 GeV synchrotron radiation facility, SPring-8, will provide high brilliance X-ray beam. Using this new X-ray source, we can study the inner shell photoionization of heavy-element ions. Knowledge of photoionization cross sections of positive ions is of importance in plasma physics, astrophysics, and atmospheric physics. Despite their importance in a number of areas, experiments on the photoionization of ions have little been studied. Recently, photoionization of positive ions have been calculated. It, however, is difficult to assess the accuracy of calculations due to the lack of experimental data..

In order to obtain experimental data on the photoionization of positive ions, we have developed a collinear photon-ion merged-beam apparatus. As a first trial, yields of multiply charged-ions produced by photoionization of Xe^+, Ba^+, and Eu^+ ions in 4*d* ionization region have been measured as a function of photon energy. The photoionization cross sections of 4*d* electron in Ba and its close neighbors in the periodic table have been of interest due to the broad absorption peaks caused by $4d$-εf excitation beyond the photoionization thresholds. These peak structures are generally termed "giant resonances". The characteristics of giant resonances depends critically on the details of the effective potential for an *f* electron. For neutral atoms with Z >57, the 4*f* wave function is in the inner well (collapsed) of the two well potential of 4*f* electron. The structure of giant resonance changes from broad $4d$-εf shape-resonance to 4*d*-4*f* discrete-resonance with increasing of Z [1]. On the other hand, Lucatorto et al. [2] measured the photo-absorption cross section of Ba, Ba^+, and Ba^{2+} near 4*d* threshold. They found several very strong discrete transitions only in Ba^{2+}, although most of the 4*d* absorption oscillator strength is in the continuum in Ba and Ba^+. They explained such behavior in term of partial collapse of the *nf* bound states in Ba^{2+}. The $4d$-ε, 4*f* photoexcitation of ions can show any difference from neutral, since a change of charge state can affect the 4*f* wave function.

2.Experimental

The details of the apparatus were described in Ref.3. Figure 1 shows a schematic diagram of the

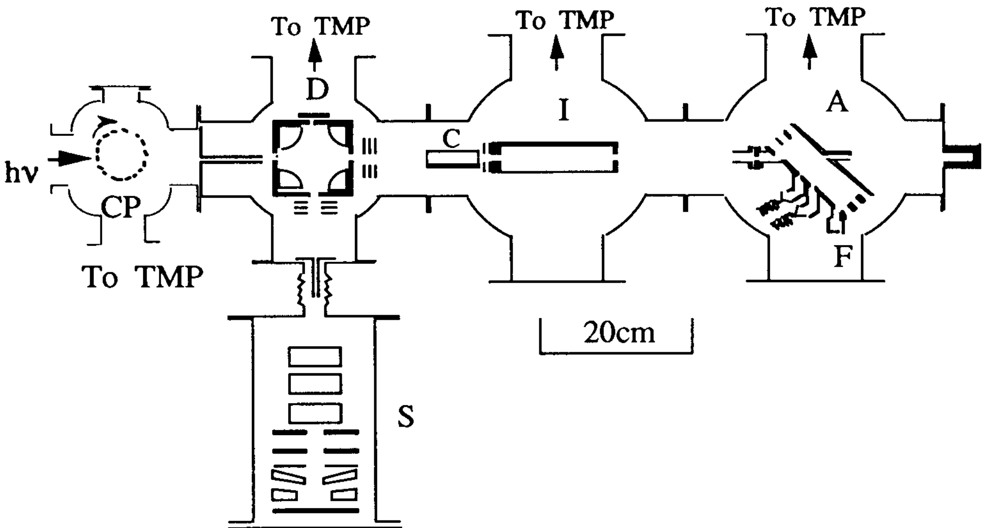

Fig. 1. Schematic diagram of the merged-beam apparatus. S:ion source, D:quadrupole ion deflector, C:collimator of ion and photon beams, I:interaction region, A:parallel plate charge-state analyzer, F:Faraday cup, CP: rotating chopper wheel for photon chopping.

apparatus. A surface ionization type ion source was used for Ba^+ and Eu^+, and an electron impact type for Xe^+. Singly charged ions produced in the ion source were accelerated up to 2 keV, and deflected 90° by a quadrupole deflector to be merged with the monochromatic photon beam. Radiation from bending magnet was mono-chromatized by a 24 m spherical grating mono-chromator in the BL-3B beam line[4] of the Photon Factory at the National Laboratory for High Energy Physics. After passing an interaction region, whose length is 15 cm, the ions were charge analyzed by a parallel plate charge-state analyzer. The interaction region was biased at potential of about +800 V to distinguish the multiply charged ions produced in this region from those produced at a different region by other charge stripping process. A Faraday cup and two single particle detectors were mounted on the analyzer. The primary ions were collected in the Faraday cup and multiply charged ions formed in the interaction region were detected by two single particle detectors. The intensity of photon beam was measured by monitoring the electron current of a gold-plated photodiode. The background pressure of 4×10^{-10} Torr was maintained during the experiment. The energy scale of monochromator and the relative photodiode efficiency were calibrated in a subsidiary experiment by measuring the total photoion yield of Kr near $3d$ threshold.

3.Results and Discussion

The relative photoion yields from photo-ionization of Ba^+ were measured in the energy range from 90 to 140 eV, which corresponds to the ionization region of $4d$ electrons. The partial yields of Ba^{2+} and Ba^{3+} are shown in Fig. 2 as a function of photon energy. The energy resolution $E/\Delta E$ of a monochromator was about 130.

The threshold energy of $4d$ ionization for Ba^+ ion has not been clearly known experimentally. This, however, is estimated at 109 eV on the basis of a Hartree-Fock calculation[5]. As shown in Fig. 2, some prominent peaks are observed below 109 eV for both Ba^{2+} and Ba^{3+}. These peaks can most probably be attributed to "resonance Auger" process. The excited Ba^{+*} ion decays to Ba^{3+} ion by two step Auger processes or by double Auger processes. If an excited electron is ejected by the first Auger process, most of intermediate excited states of Ba^{2+*} are energetically below the triple ionization threshold and, therefore, can not decay to Ba^{3+}.

The Ba^{3+} yield spectrum reveals a broad giant resonance peak due to $4d$ excitation above the ionization threshold, while no such peak is conspicuous in the Ba^{2+} spectrum. Similar broad maximum was observed also in the absorption spectrum obtained by Lucatorto et al. [2], but discrete transition structures were not clear in their spectrum.

Above the $4d$ threshold, the main process is $4d$ ionization followed by Auger decays. The doubly-charged ions are created mainly by direct outer shell(5s,5p,6s) photoionization in this energy region. Thus a giant resonance peak was seen only for Ba^{3+} spectrum as shown in Fig. 2. The yields of Ba^{2+}, however, have a small broad peak ranging from $4d$ threshold to 130 eV. This structure can be attributed to resonant enhancement of outer shell photoionization in the range of the giant resonance.

Besides the Ba^+ experiment, other ions that include Eu^+ and Xe^+ have been measured. Further analysis of the data is now in progress.

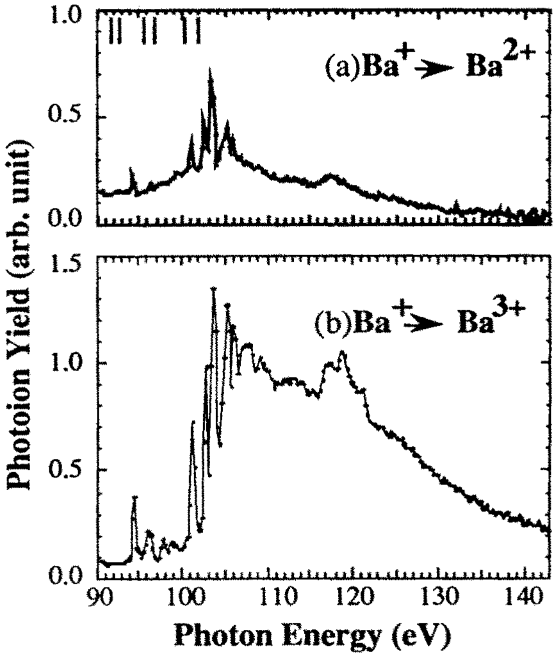

Fig. 2. Relative photoion yields from photo-ionization of Ba^+. (a) Partial yields of Ba^{2+}. (b) Partial yields of Ba^{3+}.

References

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