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Ion Charge-State Production and Photoionization Near the K Edge in Argon and Potassium

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Abstract

We have measured the time-of-flight charge distributions of ions of argon and potassium following x-ray absorption at energies near their respective K edges. We confirm previously observed enhancements of the higher charge states at energies up to 100 eV below the K edge in argon. The measurements confirm recent calculations suggesting excitation of a virtual 1s state in this energy range.

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1. Introduction

Studies of ion charge state yields following photoexcitation near inner-shell resonances can help to resolve the relative importance of the excitation and relaxation process involved in the gain and loss of energy to the atomic system.

We have studied the production of argon and potassium ions near the thresholds of their respective K-edges. Doppelfeld *et al*[1] have shown that the average ionic charge $Q(\text{ave})$ is a linearly increasing function of energy just below the K-edge of argon. The normal resonant ionization behavior would produce a Lorentzian with quadratic energy dependence away from the resonance. Amusia[2] has explained the linear energy dependence as due to the formation of virtual 1s state below the edge with consequent further ionization with a 2s or higher electron vacancy. Ueda *et al*[3] have also made a detailed study of this region.

We have made more detailed measurements of the charge state productions for argon ions from 100 volts below the K-edge to above the KM-resonances, as well as some initial measurements in potassium.

2. Experiment

The experimental layout is shown in Figure 1. The measurements took place at the Argonne/NIST X24A beam-line of the National Synchrotron Light Source at Brookhaven National Laboratory. The double-crystal monochromator gave a band-pass of about 0.5 eV at 3200 eV. The argon experiments utilized a gas nozzle in place of the oven shown for the potassium vapor jet. Time-of-flight measurements of the ions were made utilizing the single bunch operating mode of the NSLS. A multichannel analyzer recorded up to four different charge states simultaneously during each energy scan through the K edge region. Charge states +1 to +7 were recorded during successive scans, normalized using one common charge state in each scan.

3. Results

The argon results confirm quite well the measurements of Doppelfeld *et al*[1]. We estimated the effects of differing efficiencies of the ions reaching the channelplate detector with differing velocities by comparing results with different time-of-flight voltages. It appears that the work of Doppelfeld needs only a small correction to obtain the absolute charge distributions. Our relative charge yield $Q(\text{ave})$ is slightly higher due to adjustment for the correction of a lower efficiency of the lower charge states. The energy dependence of the average charge state near the K edge is shown in Figure 2. A major verification of Amusia's calculation[2] is the complete absence of the 4p resonance in the observed $Q(\text{ave})$ distribution. The slow increase of the average charge state from 100 eV below threshold is confirmed in Figure 3. The slow linear increase was also observed by Doppelfeld *et al*[1], and is in accord with Amusia's calculation of excitation of the virtual 1s state.

The individual charge state distributions show the 4p resonances strongly (Figure 4), although it is clear that the slowly increasing energy dependence below threshold can be seen in the higher charge state distributions (4 to 6) below threshold, and is also due to the virtual 1s excitation. Table I notes the individual charge state productions at energies below (3192 eV) and above (3220 eV) the K threshold. In the low energy region the higher charge states (+4 to +7)

are already increasing slowly. Further calculations are in progress to show how these charge state ratios can be understood in terms of the virtual excitation model.

Figure 5 shows a small increase in the average charge state in the KM resonance region which must be due to virtual excitations involving multiply-excited states.

The potassium ion spectra are much noisier (Figure 6) due to the much lower target density. In addition, data collection was only possible for a short time (up to 60 minutes), due to contamination of the channelplate detector from the background potassium vapor. Further improvements in the apparatus are underway to allow improved signal ratios. However, even with this reduced signal intensity, Figure 7 shows the same energy dependence of the $Q(\text{ave})$ as in the argon case.

4. Acknowledgements

We acknowledge the technical help of Barry Karlin in the measurements at the NSLS X24A beamline, and of Charles Kurtz and Bruce Zabransky for their design and construction of the alkali oven used in the potassium measurements. This research was supported by the U.S. Department of Energy, Fundamental Interactions Branch, Office of Basic Energy Sciences, Division of Chemical Sciences, under contract number W-31-109-ENG-38 (Argonne).

5. References

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Table 1. Charge state populations below and above the 1s threshold (see Fig. 4).

Charge state	Yield at 3192 eV	Yield at 3220 eV	Ratio of yields
+1	115	228	2.0
+2	514	2133	4.1
+3	921	3028	3.3
+4	349	9472	27.1
+5	92	4921	53.8
+6	21	1202	57.2
+7	8	142	(18)

Figure Captions

Figure 1. Ion time-of-flight analyzer with alkali metal oven.

Figure 2. The average charge state in argon through the K-edge.

Figure 3. The average charge state in argon down to 100 eV below the K-edge.

Figure 4. Individual argon ion charge state distributions (note the log scale).

Figure 5. The average charge state in argon near the KM resonances region.

Figure 6. Potassium time-of-flight spectrum

Figure 7. $Q(\text{ave})$ for potassium through the 4p resonance.

ION TIME-OF-FLIGHT ANALYZER WITH ALKALI METAL OVEN

Fig. 1

Averaged Argon Charge State
(efficiency-adjusted)

Argon averaged Charge state
(Below the K-threshold)

Argon Charge State Yields

Average Charge state in the KM region
 $Q_{\text{Bar}} = \text{Sum}(Q \cdot N(Q)) / \text{Sum}(N(Q))$

Fig. 6

Potassium K-edge, Charge State Production