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High resolution L Auger electron spectra from fast projectile ions studied by zero-degree electron spectroscopy

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Abstract

In 64-MeV S^{5+} + He and 90-MeV Sc^{8+} + He collisions, the light target atom He was used to excite or ionize selectively the L shell of the sulfur and scandium projectiles. The subsequent L-shell Auger emission from Na-like S^{5+} and Mg-like Sc^{9+} was measured with high resolution using zero-degree Auger spectroscopy. For 64-MeV S^{5+} + He collisions, the spectra are dominated by the line groups attributed to the configurations $1s^22s^22p^53snl$ for $n > 3$. For 90-MeV Sc^{8+} + He collisions, the spectra are dominated by the three peak groups that are attributed to the transitions from $1s^22s^22p^53s^23p$ to $1s^22s^22p^63s$, $1s^22s^22p^63p$, and $1s^22s^22p^63d$. It was found that the last Auger transition for Sc^{9+} involves three electrons via electron correlation and this result was compared with the previous results for the isoelectronic ions of Al^+ and Ar^{6+}. © 1998 Elsevier Science B.V.

Keywords: Zero-degree electron spectra; L Auger electrons; S^{5+} ions; Sc^{9+} ions; CIHF calculations

1. Introduction

High-resolution projectile Auger spectroscopy has been a powerful tool for obtaining detailed information about the structure and collision mechanism of highly ionized atoms [1,2]. In particular, zero-degree Auger spectroscopy has been used extensively to study fast projectiles whose charge state may be prepared prior to the collision [1–6]. Using light target atoms such as He, this method allows for the study of selectively excited configurations and thereby also that of specific excitation mechanisms [1–3]. Usually the low-Z target atom interacts only with one electron of the projectile ion leaving the others unchanged. Consequently, under single-collision conditions, the collision with a projectile ion of properly chosen charge state results in a few selected excited states.

In the present work, we measured sulfur L-Auger

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electrons produced in 64-MeV S^{5+} + He and scandium L-Auger electrons produced in 90-MeV Sc^{8+} + He collisions using zero-degree Auger spectroscopy. The experimental results were compared with theoretical calculations.

2. Experimental

The experimental apparatus used in these measurements has been described previously [7,8], and is shown schematically in Fig. 1. Projectiles of 64-MeV S^{5+} and 90-MeV Sc^{8+} were provided by the tandem accelerator at the Japan Atomic Energy Research Institute of Tokai. The beam was carefully collimated to about 1.5 mm in diameter to avoid slit scattering. The beam currents were 50–100 nA and were collected in the Faraday cup which were used to normalize the spectra.

The length of the target gas cell is 5 cm with an entrance and exit aperture of 3 mm diameter. Measurements were performed at a target pressure of $\sim 10^{-1}$ Pa which satisfies single-collision conditions. During operation of the gas cell, the pressure in the collision chamber was 5×10^{-3} Pa whereas that of the beam line in front of the collision chamber was $\sim 10^{-5}$ Pa.

The measurements were performed using a tandem 45° parallel plate electron spectrometer as shown in Fig. 1. The first spectrometer was used as a deflector to separate the electrons from the ion beam as well as to suppress background electrons. The second spectrometer determined the electron energy with high resolution. Entrance and exit slits of this spectrometer were separated by 50 mm and were 1.6 mm × 10 mm. The geometrical spectrometer constant is 0.6300 for the first spectrometer and 0.5908 for the second. These values were confirmed by measuring mono-energetic electrons from an electron gun and cusp electrons. To improve the electron energy resolution, the deflected electrons were decelerated in the region between the two spectrometers to 50~80 eV by a retarding electric field. Throughout the experiment, the overall energy resolution of the spectrometer was less than 3 eV, corresponding to an energy resolution of 0.1–0.4 eV in the projectile rest frame.

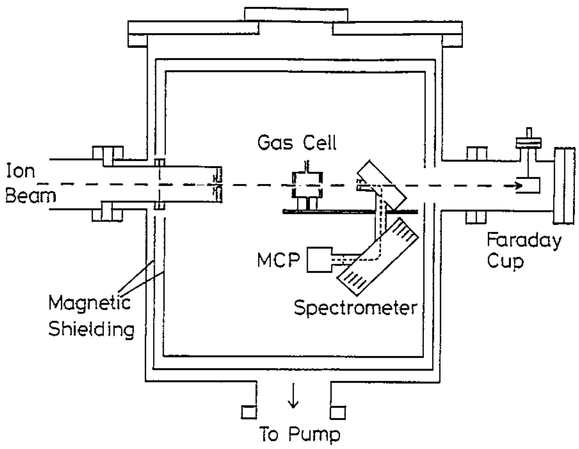

Fig. 1. Typical experimental set-up used for the method of zero-degree Auger spectroscopy.

3. Result and discussion

3.1. 64-MeV S^{5+} + He

Fig. 2 shows a low-resolution secondary electron spectrum produced in 64-MeV S^{5+} + He collisions. A cusp-shaped peak at 1.08 keV is mainly due to the electron loss to the continuum (ELC). A few peaks in the low and high energy wings of the cusp come from projectile L-Auger electrons emitted at 180° and 0° in the projectile frame, respectively. High-resolution L-Auger spectra obtained at a pass energy of 80 eV are shown in Figs 3 and 4. The projectile S^{5+} ions with the initial configuration $1s^2 2s^2 2p^6 3s$ were selectively excited by a He target and a 2p electron

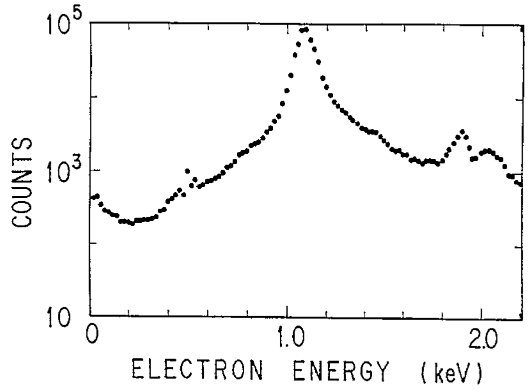

Fig. 2. Low-resolution electron spectrum produced in 64-MeV S^{5+} + He collisions. The energy refers to the laboratory frame.

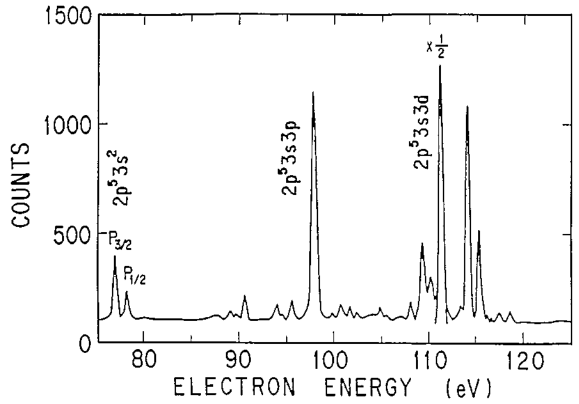

Fig. 3. High-resolution L-Auger spectrum produced in 64-MeV S^{5+}+He collisions. The energy refers to the projectile rest frame.

vacancy was produced in S^{5+} ions at this collision energy. These excited states decayed via emission of L-Auger electrons. The spectra show line groups attributed to the configurations $1s^22s^22p^53snl$ for $n > 3$. As can be expected, the most prominent line group is attributed to the configuration $1s^22s^22p^53s3d$ which is excited via a dipole transition 2p–3d. It is noted that the quadrupole transition $1s^22s^22p^63s–1s^22s^22p^53s3p$ is also significant. The $^2P_{1/2}–^2P_{3/2}$ fine-structure splitting is clearly seen in the doublet structure (at ~77 eV) due to the $1s^22s^22p^53s^2$ configuration. The spectra were reproduced by transition energies and intensities calculated using the configuration-interaction Hartree-Fock (CIHF) code developed by Cowan [9]. It is found that the measured spectra are due to the decay of configurations produced by monopole, dipole, and quadrupole excitation of both 2s and 2p electrons. The structure of the excited states and the population and decay of the states produced in these collisions are strongly influenced by the mixing of different multiplet states and by the configuration interaction [10].

3.2. 90-MeV Sc^{8+} + He

Recently, L-Auger spectra of Al^+ [11] and Ar^{6+} [6] have been studied in detail. In both cases, three decay channels have been observed, which are attributed to transitions from $1s^22s^22p^53s^23p$ to $1s^22s^22p^63s$, $1s^22s^22p^63p$ and $1s^22s^22p^63d$. The last transition to $1s^22s^22p^63d$ can be reached only in a three-electron rearrangement process. The measured line energies and intensities have been compared with theoretical results evaluated by the CIHF program by Cowan [9]. It was found that the agreement between experimental and theoretical data for the $2p^63d$ final configuration decreased from Al^+ to Ar^{6+} while on simple grounds the opposite behavior had been expected.

In order to study the change in the branching ratios, systematically, we have carried out experiments for the heavier isoelectronic system, Sc^{9+} [12]. Fig. 5 shows the L-Auger spectrum produced in 90-MeV Sc^{8+} + He collisions. The spectrum exhibits a pair of peaks at 142.8 eV and 147.4 eV which are attributed to the $^2P_{3/2}–^2P_{1/2}$ doublet formed by the initial configuration $1s^22s^22p^53s^2$ of Na-like Sc^{10+} ions. The remainder of the spectral intensity is due to the initial configuration $1s^22s^22p^53s^23p$ of Mg-like Sc^{9+} ions.

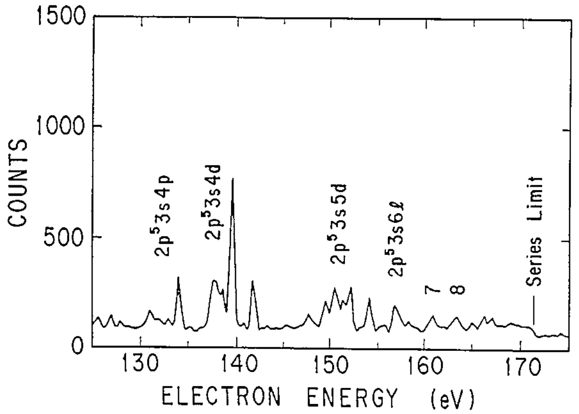

Fig. 4. High-resolution L-Auger spectrum produced in 64-MeV S^{5+}+He collisions. The energy refers to the projectile rest frame.

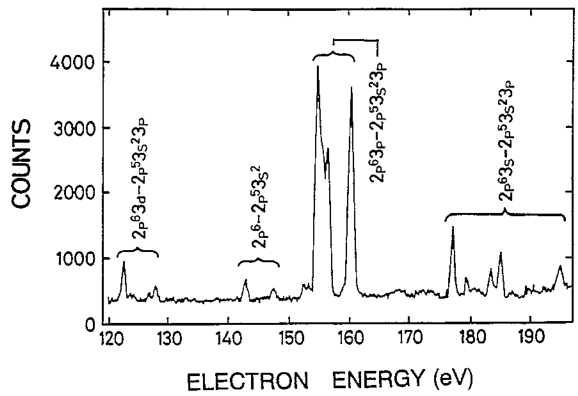

Fig. 5. High-resolution L-Auger spectrum produced in 90-MeV Sc^{8+} + He collisions. The energy refers to the projectile rest frame.

Table 1
Intensities of Auger line groups attributed to the different final states. Theoretical values were calculated with the configuration-interaction Hartree-Fock program of Cowan [9], which included n = 2 and 3 correlation in the initial state. Al^{+} and Ar^{6+} are from Refs. [11] and [6], respectively

Final state	Experimental	Theoretical
Al^{+} ion		
$1s^2 2s^2 2p^6 3s$	45	49
$1s^2 2s^2 2p^6 3p$	39	40
$1s^2 2s^2 2p^6 3d$	16	11
Ar^{6+} ion		
$1s^2 2s^2 2p^6 3s$	18.4	21.5
$1s^2 2s^2 2p^6 3p$	72.4	68.2
$1s^2 2s^2 2p^6 3d$	9.2	10.3
Sc^{9+} ion		
$1s^2 2s^2 2p^6 3s$	19.0	18.5
$1s^2 2s^2 2p^6 3p$	75.0	75.0
$1s^2 2s^2 2p^6 3d$	6.0	6.0

Three peak groups with centroid energies near 125 eV, 157 eV and 181 eV are associated with transitions to the final state configurations $1s^2 2s^2 2p^6 3d$, $1s^2 2s^2 2p^6 3p$ and $1s^2 2s^2 2p^6 3s$, respectively.

The individual decay rates for the transitions in the Sc L-Auger peaks were calculated using the CIHF program [9]. The results for the branching ratios are shown in Table 1 together with the experimental data. The calculations differed from those carried out for the analogous cases of Al [11] and Ar [6] by including not only correlation in the n = 3 shell but also correlation in the n = 2 shell. For Sc there is agreement with the experiment within experimental error limits when the n = 2 and n = 3 correlations in the initial state are included. For Ar, the agreement is considerably improved but still not perfect. However, it can be expected that including only correlation in the initial state will give a better description of a highly ionized system than of a less ionized one. This is partly because the final ionic states $1s^2 2s^2 2p^6 nl$ are fairly simple and partly because the Auger electrons have higher and higher energies with increasing ionization which makes interaction in the final continuum state less and less likely.

Acknowledgements

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References

[1] N. Stolterfoht, Phys. Rep. 146 (1987) 317.
[2] N. Stolterfoht, J. Electron Spectrosc. Relat. Phenom. 67 (1994) 309.
[3] A. Itoh, T. Schneider, G. Schiwietz, Z. Roller, H. Platten, G. Nolte, D. Schneider, N. Stolterfoht, J. Phys. B16 (1983) 3965.
[4] A. Itoh, D. Schneider, T. Schneider, T.J.M. Zouros, G. Nolte, G. Schiwietz, W. Zeitz, N. Stolterfoht, Phys. Rev. A31 (1985) 684.
[5] N. Stolterfoht, P.D. Miller, H.F. Krause, Y. Yamazaki, J.K. Swenson, R. Bruch, P.F. Dittner, P.L. Pepmiller, S. Datz, Nucl. Instrum. Methods B24/25 (1987) 168.
[6] P. Focke, T. Schneider, D. Schneider, G. Schiwietz, I. Kádár, N. Stolterfoht, J.E. Hansen, Phys. Rev. A40 (1989) 5633.
[7] K. Kawatsura, M. Sataka, Y. Yamazaki, K. Komaki, Y. Kanai, H. Naramoto, K. Kuroki, T. Kambara, Y. Awaya, Y. Nakai, N. Stolterfoht, Nucl. Instrum. Methods B48 (1990) 103.
[8] K. Kawatsura, M. Sataka, H. Naramoto, M. Imai, K. Komaki, Y. Yamazaki, K. Kuroki, Y. Kanai, T. Kambara, Y. Awaya, J.E. Hansen, I. Kádár, N. Stolterfoht, Nucl. Instrum. Methods B53 (1991) 421.
[9] R.D. Cowan, The Theory of Atomic Structure and Spectra, University of California Press, Berkeley, CA, 1981.
[10] I. Kádár, H. Altevogt, R. Köhrbrück, V. Montemayor, A. Mattis, G. Schiwietz, B. Skogvall, K. Sommer, N. Stolterfoht, K. Kawatsura, M. Sataka, Y. Nakai, H. Naramoto, Y. Kanai, T. Kambara, Y. Awaya, K. Komaki, Y. Yamazaki, Phys. Rev. A44 (1991) 2900.
[11] R. Malutzki, A. Wachter, V. Schmidt, J.E. Hansen, J. Phys. B20 (1987) 5411.
[12] M. Sataka, K. Kawatsura, H. Naramoto, Y. Nakai, Y. Yamazaki, K. Komaki, K. Kuroki, Y. Kanai, T. Kambara, Y. Awaya, J.E. Hansen, I. Kádár, N. Stolterfoht, Phys. Rev. A44 (1991) 7290.