AUGER TRANSITIONS IN Li-LIKE AND Be-LIKE IONS

R. BRUCH, G. PAUL, J. ANDRÄ
Freie Universität Berlin, Institut für Atom- und Festkörperphysik A, 1 Berlin 33, Boltzmannstr. 20, Germany

and

B. FRICKE
Gesamthochschule Kassel, 35 Kassel, Heinrich-Plettstr. 40, Germany

Received 9 May 1975

Measurements of the Auger decay of beam-foil excited BeII and BeI levels are reported along with a proposed assignment of the experimental spectra. The LiI, BeII and BeIII $(1s\,2s^2)^2S \rightarrow (1s^2\,2s)^2S$ Auger transitions as presented in this letter represents the first observation of such states in positive ions with $Z \leqslant 5$.

The beam-foil or beam-gas interaction creates inner and outer shell multiply excited target and projectile states with high efficiency [1]. Such highly excited levels deexcite mainly by two competing processes: the emission of photons and the ejection of Auger electrons [2]. Recently the Ne K-shell ionization in 50 MeV $Cl^{n+} \rightarrow$ Ne collision $(5 \leqslant n \leqslant 15)$ were investigated by Burch and coworkers [3]. Independently Mowat et al. [4] studied He-like, Li-like, Be-like and B-like neon K X-ray structure induced by 80 MeV argon-ion impact. Fortner et al. [5] have measured B X-ray spectra after impact excitation, which revealed information on one, two and three electron series of boron.

In the present letter, Coulomb autoionization of three, four and five electron systems of the kind $(1s\,2s^2\,2p^n)(1s\,2s\,2p^{n+1})$ and $(1s\,2p^{n+2})\,(n = 0, 1, 2)$ for light atoms with $Z \leqslant 5$ will be considered. To our knowledge no Be and B electron spectra of the type mentioned above have been reported previously. We present here beryllium autoionization line structure due to decays of foil excited Be I and Be II atoms. An important feature of the beam-foil technique [1] is the excellent time resolution $(\Delta t \sim 10^{-10}$sec) which permits the separation of Coulomb (prompt) and metastable (delayed) autoionizing transitions by moving the foil in and out of the viewing region of an electron spectrometer.

The decays of the Be projectiles were measured in flight with a cylindrical high transmission $(T \sim 1\%)$ electrostatic analyser [6] accepting electrons at $42.3 \pm 1°$. With $7\,\mu g/cm^2$ thick C-foils we thus achieved an effective FWHM-resolution of 1.7%. We could observe the

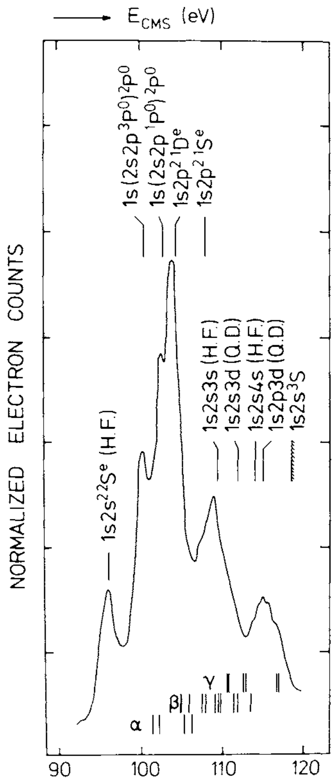

Fig. 1. Auger electron spectrum between 90 and 120 eV for 300 keV $Be^+ \rightarrow$ C-foil collisions. (H.F.) = Hartree–Fock, (Q.D.) = Quantum Defect. α: $(1s\,2s^2\,2p)^{3,1}P^0 \rightarrow (1s^2\,2s\epsilon p)^{3,1}P^0$ or $(1s^2\,2p\,\epsilon s)^{3,1}P^0$; β: $(1s\,2s\,2p^2)^{3,1}D^e, {}^{3,1}P^e, {}^{3,1}S^e \rightarrow (1s^2\,2p\epsilon p)^{3,1}D^e, {}^{3,1}P^e, {}^{3,1}S^e$; $(1s\,2s\,2p^2)^{3,1}D^e \rightarrow (1s^2\,2s\epsilon d)^{3,1}D^e$; $(1s\,2s\,2p^2)^{3,1}S^e \rightarrow (1s^2\,2s\epsilon s)^{3,1}S^e$; γ: $(1s\,2p^3)^{3,1}D^o \rightarrow (1s^2\,2p\epsilon d)^{3,1}D^o$; $(1s\,2p^3)^{3,1}P^o \rightarrow (1s^2\,2s\epsilon p)^{3,1}P^o$ or $(1s^2\,2p\epsilon s)^{3,1}P^o$.

Table 1
Observed and calculated energies (eV) for the $(1s\,2s^2)^2S^e \rightarrow (1s^2\epsilon s)^2S^e$ Auger transition in Li I, Be II and B III.

	Experimental	Theory
Li I	50.6 ± 0.5 a)	51.12 a) 51.16 b)
Be II	95.8 ± 0.5 a)	96.25 a) 96.27 b)
B III	154.5 ± 0.5 a)	155.01 a) 155.09 b)

a) This work (HFS)
b) Safronova et al. [8].

prompt and delayed Be electron spectra successively with the same foil [7]. The well-known metastable autoionizing Be II transition $(1s\,2s\,2p)^4P^0_{5/2} \rightarrow (1s^2\epsilon f)^2F^0_{5/2} + 0.1$ eV [1] has been used to calibrate the prompt Be spectra.

In fig. 1 the prompt electron energy spectrum (cms-system) in the energy range 90–120 eV for 300 keV $Be^+ \rightarrow$ C-foil collisions is indicated. Beryllium is of particular interest since it is the simplest atom where multiple excited four electron levels can arise. In order to identify our spectra we have estimated some Be II energies using (a) Hartree–Fock–Slater wave functions and (b) the quantum defect method [2]. Part of the Be II and Be I transition energies as indicated in fig. 1 were deduced from second order perturbation theory [8]. Owing to the predicted equilibrium charge distribution [9] one would suspect that decays of multiply excited Be III, Be II and Be I levels might contribute to the measured Auger spectrum. It has been shown [7] that Auger peaks due to deexcitation of doubly excited $2lnl'$ $(n \geqslant 2)$ Be III and triply excited $2lnl'ml''$ $(n, m \geqslant 2)$ Be II levels appear at energies $E_{cms} \geqslant 120$ eV. Thus the line structure displayed in fig. 1 must be attributed to decays of initial Be II and Be I configurations with one K-shell vacancy. Such configurations are, in order of increasing energy:

$1s\,2s^2$, $1s\,2s\,2p$, $1s\,2p^2$ (Li-like)

and

$1s\,2s^22p$, $1s\,2s\,2p^2$, $1s\,2p^3$ (Be-like) .

The first peak in the Be-spectrum at about 96 eV is consistent with the expected $(1s\,2s^2)\,S^2 \rightarrow (1s^22s)^2S$ Auger transition in Be II. Furthermore the theoretical energy positions associated with decays of $1s(2s\,2p^{3,1}P)^2P^0$ and $(1s\,2p^2)^1D^e$, $^1S^e$ appear to correspond to the observed line structure between 100–110 eV. However, Auger transitions arising from four electron Be I configurations such as (α) $1s\,2s^22p$, (β) $1s\,2s\,2p^2$ and (γ) $1s\,2p^3$ might contribute to the spectrum as well. The boron electron spectra [10] are somewhat more complex due to additional decays of BI five electron configurations of the kind $1s\,2s^22p$, $1s\,2s\,2p^3$ and $1s\,2p^4$ respectively. Nevertheless, the peak due to decays of $(1s\,2s^2)^2S$ in BIII could be identified. These data represent the first experimental energy values of the $(1s\,2s^2)^2S^e$ level up to the fourth member of the He^- isoelectronic sequence [11] as summarized in table 1.

The analysis of the Li, Be and B spectra demonstrates that it is possible to extract information about highly excited states produced by beam-foil collisions. However, to enhance the resolution of the spectra it seems desirable to use slightly higher impact energies of about 1–2 MeV.

This work has been supported by the Sonderforschungsbereich 161 of the Deutsche Forschungsgemeinschaft.

References

[1] I. Martinson and A. Gaupp, Physics Reports 15C (1974).
[2] M.E. Rudd and J.H. Macek, Case Studies in Atomic Physics III (1974) 49.
[3] D. Burch et al., Phys. Rev. Lett. A32 (1974) 1151.
[4] J.R. Mowat et al., Phys. Rev. A10 (1974) 1446.
[5] R.J. Fortner, J.D. Garcia and H. Oona, Phys. Lett. A47 (1974) 93.
[6] R. Bruch, G. Paul, J. Andrä and L. Lipsky (to be published).
[7] R. Bruch, G. Paul, J. Andrä and B. Fricke, Symposium on Electron and photon interactions with atoms, Stirling Scotland (1974) in print.
[8] U.I. Safronova and V.N. Kharitonova, Opt. Spectrosc. 27 (1969) 300.
[9] J.B. Marion and F.C. Young, Nuclear reaction analysis (North-Holland Company 1968) p. 39.
[10] R. Bruch, G. Paul and J. Andrä (to be published).
[11] G. Schulz, Rev. Mod. Phys. 45 (1973) 415.