UM-P-80/15

MRN AU8105065

L-SHELL IONIZATION BY RELATIVISTIC ELECTRONS

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Abstract

Measurements of the relative x-ray production cross-sections L_α/L_ℓ, L_β/L_α and L_γ/L_α by relativistic electrons for the heavy elements Gd, Tm, Ta, Au, Pb, Bi and Th have been carried out. The ratios L_β/L_α and L_α/L_ℓ are compared with previous experimental and theoretical work.

Calculations by Scofield[1] have predicted emission rates for all the intense transitions to the L-shell, using Hartree-Fock wave functions and a Hartree-Slater potential from which the relative x-ray production cross sections to a given subshell have been evaluated.

The L_3 subshell is the simplest one, as no vacancies can be filled by electrons coming from another L-subshell. The L_ℓ and L_α x-rays both result from transitions to the L_3 subshell, and therefore the ratio of their intensities should be independent of the energy of the exciting particles and method of excitation, provided multiple ionization of a single atom does not occur.

Further, questions of the energy dependence of the L_β/L_α ratio for ionization by relativistic electrons have been addressed by H. Genz et al[2,3], and therefore measurements of both this ratio and the L_γ/L_α intensity ratio have been made.

Targets consisting of Gd, Tm, Ta, Au, Pb, Bi and Th foils ranging in thickness from 4 to 25 μm were bombarded with electrons from the Melbourne betatron at energies of 10, 15.3 and 22 MeV. The betatron delivers pulses of electrons which are less than 1 μs in duration and are spaced 20 ms apart. The electron beam is transported to the target chamber and focussed with a system of quadrupole lenses and a single dipole bending magnet. Extensive shielding was employed in order to minimize the bremsstrahlung background originating primarily from the electron extraction process in the accelerator.

The characteristic atomic de-excitation L x-rays were observed with an Ortec Model 8113 Germanium Low Energy Photon Spectrometer (LEPS). The resolution of the detection system was found to be approximately 300 eV. A thin mylar x-ray port on the target chamber, the 0.13 mm Be window of the detector, and the Au dead layer on the front surface of the detector crystal were primary absorbers in the path of the x-rays. X-rays were detected at 135^o to the direction of the incident beam, and the L-shell x-ray spectra were accumulated in 1024 channels. Due to the long recovery time (~50μs) of the detector pre-amplifier compared with the beam duration, all photons detected within the beam burst are counted as a single event having energy equal to that of all photons arriving at the detector. An average counting rate of one count per beam burst was considered optimum to minimize this coincident 'pileup'. This count rate corresponded to an average beam current of 10 pA. A counting gate enabled the detector only during the beam burst.

The areas under spectral peaks were evaluated by fitting gaussians and a flat background to the PHA data. The FWHM of the fitted gaussians were in good agreement with the system resolution as measured. The peak areas were corrected for self-absorption of x-rays in the target absorption in windows, and for detector efficiency. All absorption corrections used the total photon absorption cross sections of Veigele[4].

The detector efficiency was calculated using the method of Axel[5] for low energy photons entering a large crystal near the centre of one of its flat surfaces. The calculated detector efficiency was checked against measurements previously made with a Si(Li) detector, which has a 'flat' efficiency in the region of the Ge K-absorption edge, where there is a discontinuity in the LEPS efficiency. No attempt is made to evaluate the primary vacancy distribution as the required Coster-Kronig and Fluorescence yields[6] are not sufficiently well known.

In fig.1 the ratio L_α/L_ℓ is plotted against atomic number. In the region of atomic number greater than or equal to 73 the ratio L_α/L_ℓ is in agreement with both other experimental work[7][8][9] and the theoretical values predicted by Scofield[1]. However for Gd(Z=64) and Tm(Z=69) the L_α/L_ℓ ratio measured in this work is far below the predictions of Scofield while being in substantial agreement with other experimental work[10].

In fig.2 the ratios L_β/L_α for Tm, Ta, Au, Pb and Bi are plotted as a function of energy. Comparison is made with the results of Genz et al[2], Middleman et al[1], Schlenk et al[12] and Park et al[13]. Excellent agreement is obtained in most cases, the exception being for Au and Pb where these results agree with those of Schlenk et al, but are in some dispute with Middleman et al and Genz et al respectively.

The ratio L_γ/L_α is little studied; however Middleman et al[11)] have given values for this ratio which are in rough agreement with our results.

Data have been obtained for the L x-ray intensity ratios $\frac{L_\alpha}{L_\ell}$, $\frac{L_\beta}{L_\alpha}$, $\frac{L_\gamma}{L_\alpha}$ for elements with L between 64 and 90, and for electron energies between 10 and 22 MeV. The value of the ratio L_α/L_ℓ predicted by Scofield for elements close in atomic number to Gd and Tm is too high; this has been observed by McCrary et al[9)] as well as in present work.

This work does little to support the assertion of Genz et al[2)] that the ratio L_β/L_α increases by 14% in the range 0.3-900 MeV, as there is no observable increase in the ratio L_β/L_α between these results at 10 MeV and those of Middleman et al at 900 MeV for most of the elements studied. The behaviour of the ratio L_β/L_α with respect to energy as calculated by Genz et al[2)] using theoretical subshell ionization cross-sections by Scofield[14)], Coster-Kronig and Fluorescence yields from Bambynek et al[6)] is quite uncertain as these yields are poorly known and the subshell ionization cross-sections are not predicted to an accuracy of better than 5%.

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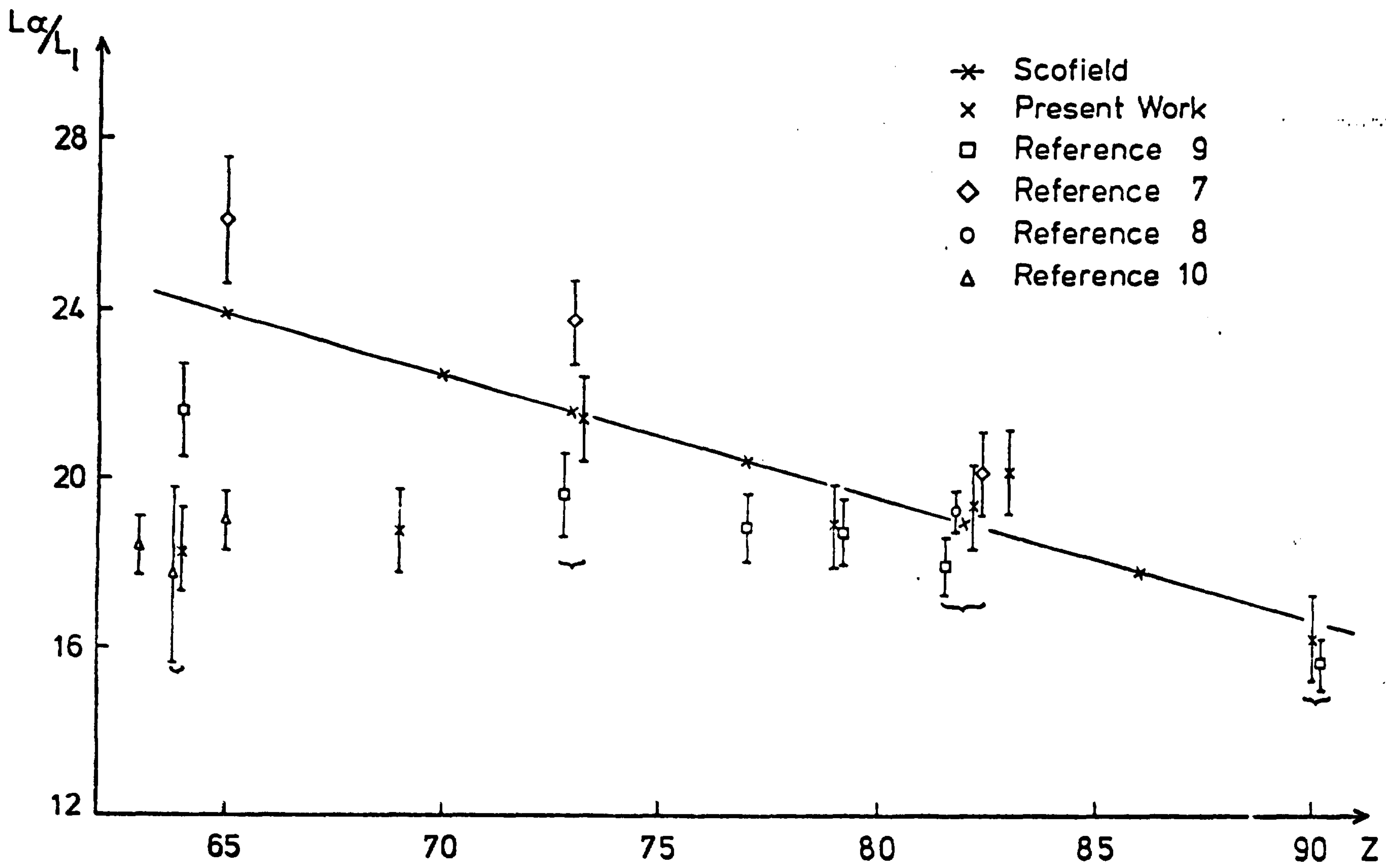
Figure Captions

Figure 1

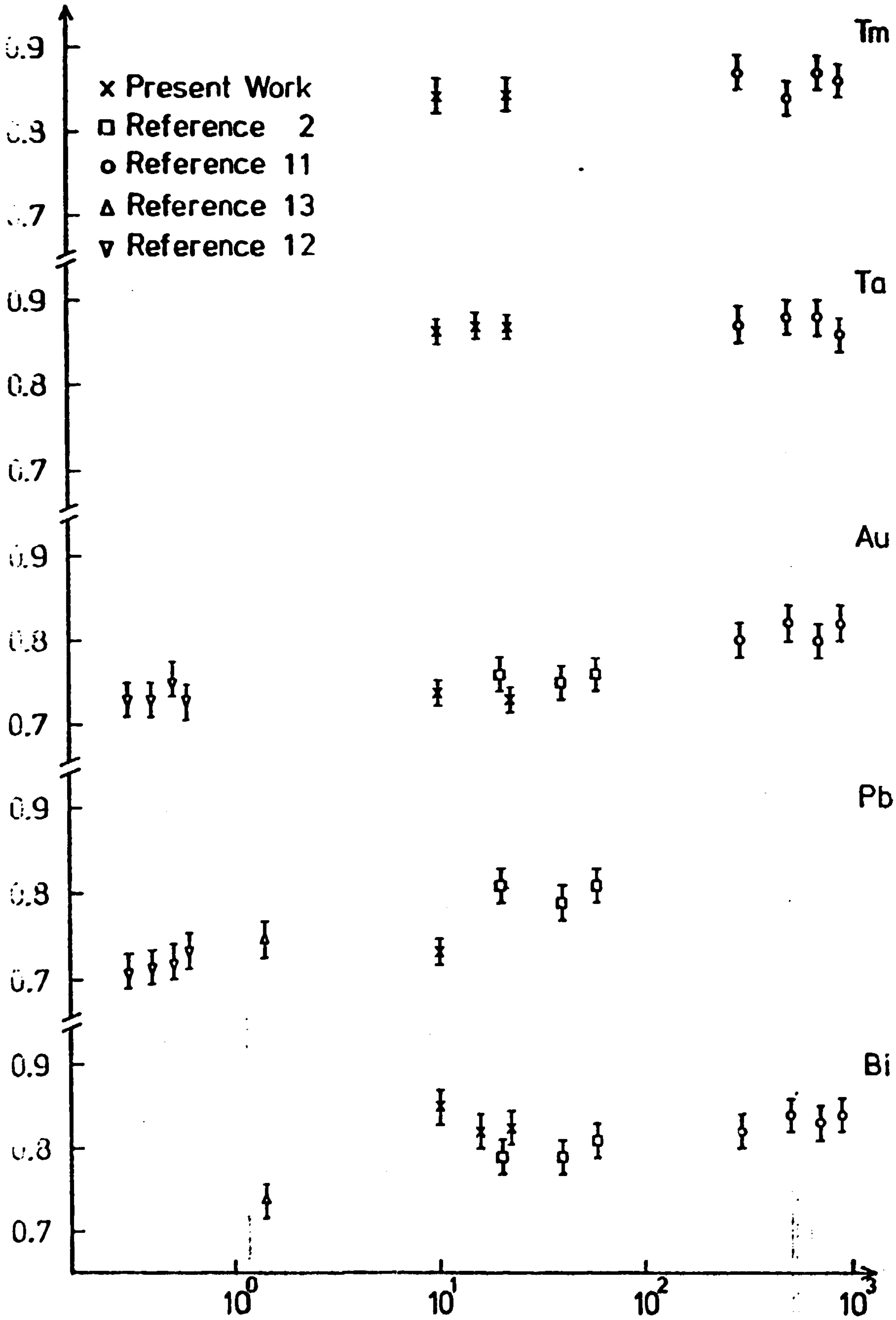
Plot of the intensity ratio $\frac{L_\alpha}{L_\ell}$ as a function of atomic number.

Figure 2

Plot of the $\frac{L_\beta}{L_\alpha}$ ratio versus electron energy for five targets.



Lα/L_l
28
24
20
16
12
65
70
75
80
85
90
Z
Scofield
Present Work
Reference 9
Reference 7
Reference 8
Reference 10



Tm
Ta
Au
Pb
Bi
x Present Work
□ Reference 2
o Reference 11
Δ Reference 13
∇ Reference 12
0.9
0.8
0.7
10^0
10^1
10^2
10^3