3.C

Nuclear Physics **A295** (1978) 211–220; © *North-Holland Publishing Co., Amsterdam*

THE ELECTRON CAPTURE DECAY OF ^{131}Ba

J. VAN PELT, C. P. GERNER, O. W. DE RIDDER and J. BLOK

Vrije Universiteit, Amsterdam, The Netherlands

Received 11 July 1977

(Revised 21 October 1977)

Abstract: The decay of ^{131}Ba has been investigated by means of a 4π internal source scintillation spectrometer and a Ge(Li) detector. The L/K and M/L electron capture ratios of the allowed transitions to the 373, 620 and 1048 keV levels in ^{131}Cs have been measured. From these electron capture ratios, the Q_{EC} value and the exchange and overlap corrections $X^{L/K}$ and $X^{M/L}$ have been derived.

E | RADIOACTIVITY ^{131}Ba; measured $I_X + I_{Auger}$, γX-coin; deduced L/K, M/L, Q_{EC}. Ge(Li), NaI(Tl) detectors. Internal source method.

1. Introduction

Several compilations of experimental electron capture ratios and comparisons with theoretical data including exchange and overlap corrections have been made recently [1,2]. The most recent one [2]), in which only very accurate measurements have been selected, shows a reasonable agreement between experimental and theoretical electron capture ratios. The decay of ^{131}Ba has been studied to investigate the suggestion of Goverse that the systematic discrepancy between experimental and theoretical exchange and overlap corrections for L/K capture ratios in his compilation is the result of correlation effects [1]).

The decay scheme according to the recent compilation by Nuclear Data Sheets [3]) is given partially in fig. 1. In the decay of ^{131}Ba, only one L/K capture ratio has been measured by Smith and Joshi in a X-γ coincident measurement with a NaI(Tl) γ-detector [4]).

An accurate Q_{EC} value is necessary for the determination of exchange and overlap corrections from electron capture ratios. The Q_{EC} values given by Wapstra and Gove (1340 ± 19 keV) [5]) and by Nuclear Data Sheets (1348 ± 7 keV) [3]) have been determined indirectly by means of the closed cycle method. Recently, Gehrke *et al.* [6]) have measured the EC/β^+ ratio to the 216 keV level in ^{131}Cs from which value they have derived a Q_{EC} value of 1372^{+10}_{-20} keV. However, the determination of this Q_{EC} value from the EC/β^+ ratio is dependent on the exchange and overlap corrections used. As we need a Q_{EC} value determined independently of exchange and overlap corrections, we have derived the Q_{EC} value from our experimental data.

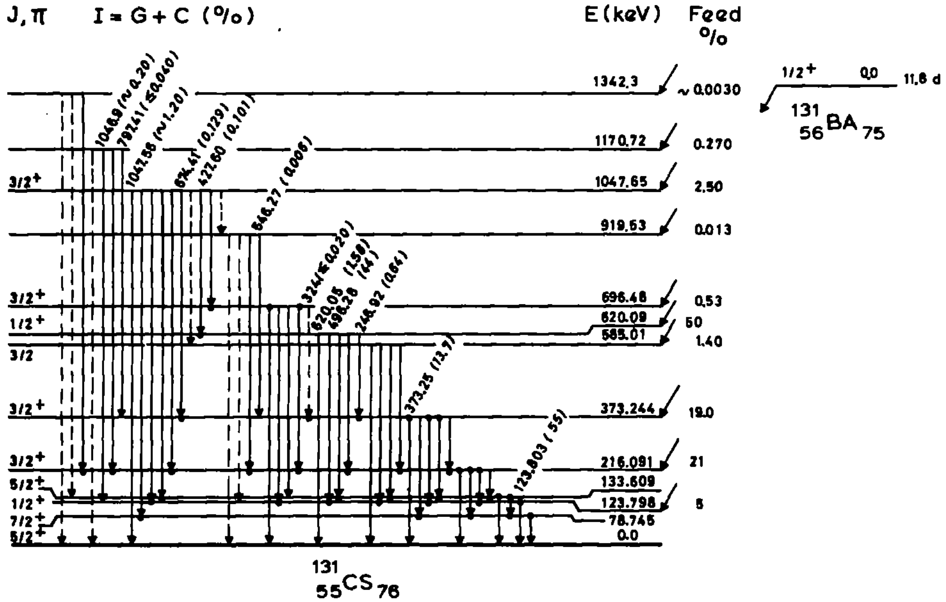

Fig. 1. Decay scheme of ^{131}Ba.

To determine Q_{EC} and $X^{L/K}$ from L/K capture ratios, at least two L/K capture ratios are needed, preferably with a very different Q_{EC} dependence. In the present work the L/K capture ratios to the 373 and 1048 keV levels have been measured very accurately. From these data the Q_{EC} value and $X^{L/K}$ are derived. The L/K capture ratio to the 620 keV level has been measured for comparison with the work of Smith and Joshi. The M/L capture ratios to the 373, 620 and 1048 keV levels have been measured to determine $X^{M/L}$.

The 11.8 d ^{131}Ba activity was bought twice from The Radiochemical Centre, Amersham. In one case a small contamination of 7.2 y ^{133}Ba activity was observable.

2. Measurements

A 4π internal source NaI(Tl) spectrometer has been used to measure X-rays and Auger electrons [7]). The γ-rays, escaping from the crystal, have been measured with a 75 cm^3 Ge(Li) detector. Apart from some differences, the experimental set-up is the same as described in previous papers [8-10]). The differences are:

(a) No use has been made of a coincidence criterion to discriminate against photomultiplier and electronic noise for the following reason. The setting of the discriminators, producing the gate signals, is limited in the low voltage region due to the noise counting rate. As the energy of the M-peak is very low, viz. 1.2 keV, some M-pulses would not trigger the discriminators, resulting in a reduction of the counting rate in the M-peak.

(b) During every measurement the γ-peak within the setting of the single-channel analyzer has been recorded by a seperate ADC. The window has been set in such a way that it selects the γ-peak and a small part of the background at the high energy side of the γ-peak. With this extension in the experimental set-up it was possible to check the position of the window during the measurements which often went on for a week. In addition, the total background within the channel could be determined by means of the background level at the high energy side of the γ-peak.

Coincidence measurements have been performed with the 373, 620 and 1048 keV γ-rays. As all these γ-rays are from ground state transitions, no coincident summation occurs in the X-ray spectra. The coincident L-K and M-L spectra only consist of the K-, L- and M-peak positioned at their binding energy. Coincidence measurements with the intense 496 keV γ-ray de-exciting the 620 keV level show in the X-ray spectra coincident summation of the 124 keV γ-ray with the X-rays. Additional coincidence measurements have been performed with the window selecting a small part of the background at the high energy side of the 373, 620 and 1048 keV peaks. The contents of the K-, L- and M-peaks have to be corrected for contribution coincident with the background in the γ-peak selecting window. This contribution consists of true and of random coincidences, as the background in the γ-peak selecting window comes from Compton radiation of more energetic γ-rays in the ^{131}Ba decay and from real background radiation. The correction has been determined by multiplying the total background within this window by the count rate in the corresponding background coincident spectrum.

In some measurements a very small 382 keV γ-peak was observable from the ^{133}Ba contamination. Attention has to be paid to exclude the 382 keV γ-peak from the window selecting the 373 keV γ-peak, as the window in the background coincident measurements also excludes the 382 keV γ-peak.

3. Results

Typical coincident spectra are given in fig. 2.

3.1. L/K CAPTURE RATIO TO THE 1048 keV LEVEL

The L/K measurements coincident with the 1048 keV γ-ray (fig. 2g) result in a L/K capture ratio of 0.165 ± 0.001. The correction in this ratio for background coincident contribution never exceeds 0.64 %. The 1047 keV γ-ray de-exciting the 1171 keV level in ^{131}Cs was not separable from the 1048 keV γ-ray. However, the calculated interference of the L/K capture ratio to the 1171 keV level in the L/K capture ratio to the 1048 keV level is about 0.02 % and hence negligible.

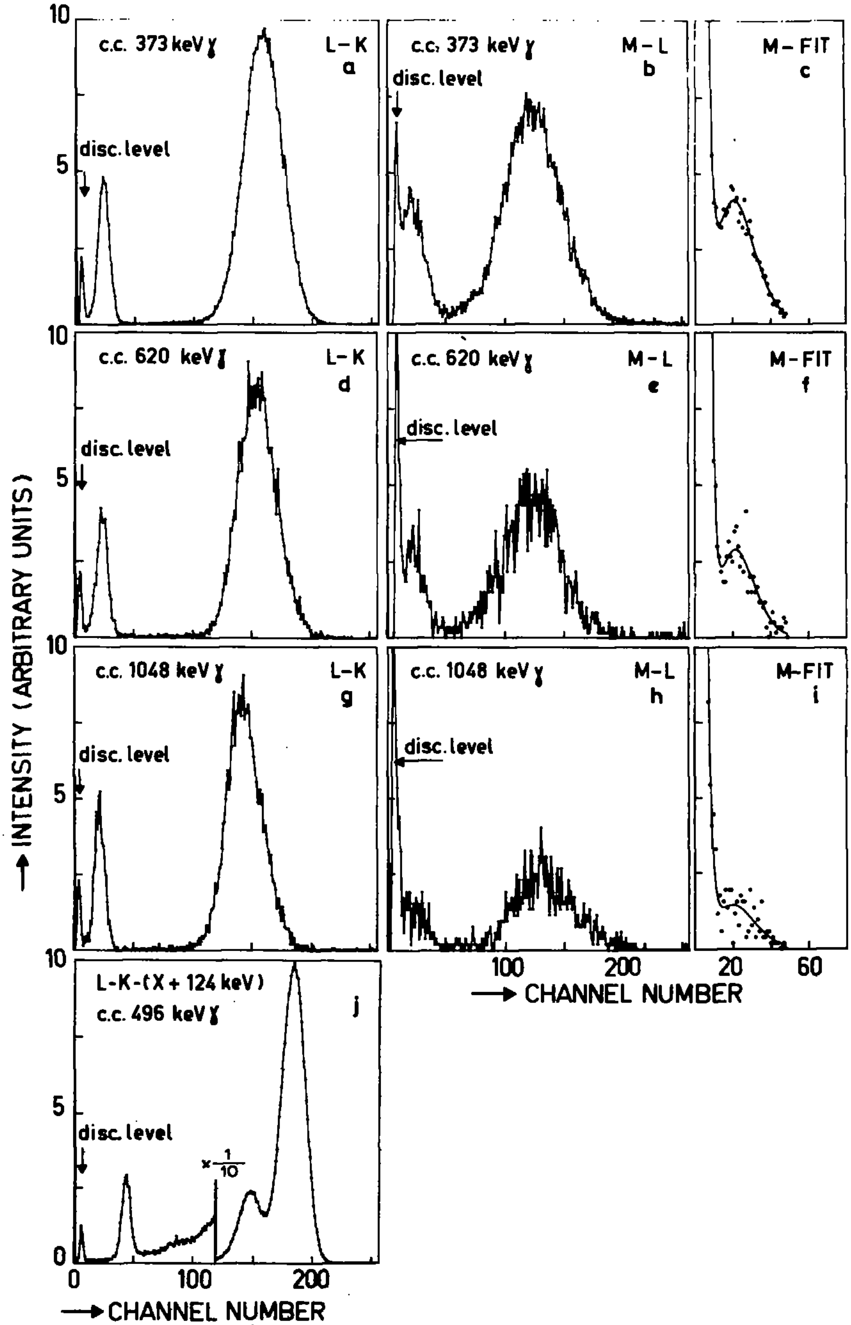

Fig. 2. Typical coincident spectra: (a), (b) coincident with 373 keV γ-ray; (d), (e) coincident with 620 keV γ-ray; (g), (h) coincident with 1048 keV γ-ray; (j) coincident with 496 keV γ-ray.

3.2. L/K CAPTURE RATIO TO THE 620 keV LEVEL

The spectrum coincident with the 496 keV γ-ray (fig. 2j) shows a peak complex due to coincident summation of 124 keV γ-rays with X-rays. At the same time a small single L- and K-peak and a finite area between these single peaks and the peak complex are visible. This is an indication that the 124 keV γ-ray has a small chance to escape totally or partially from the crystal assembly. As the contribution to the peak complex of X-rays summed up with partially detected 124 keV γ-rays is unknown, it was not possible to analyse the peak complex.

The L/K capture ratio as result of the measurements coincident with the 620 keV γ-ray is 0.149 ± 0.003 (fig. 2d). The correction in this ratio for background coincident contribution never exceeds 0.51 %. The 620 keV level is fed by electron capture decay and by de-excitation of the 1048 keV level. Only in the case of complete escape of the 428 keV γ-rays from the crystal assembly will there be a contribution to the X-peaks with a L/K ratio characteristic for the 1048 keV level. In the case of partial or total detection of the 428 keV γ-rays there will be coincident summation with the X-rays and no contribution to the X-peaks will occur. The correction to the L/K capture ratio is calculated to be about 0.008 % and hence negligible.

3.3. L/K CAPTURE RATIO TO THE 373 keV LEVEL

The L/K capture ratio as result of the measurements coincident with the 373 keV γ-ray (fig. 2a) is 0.1438 ± 0.0010. The correction in this ratio for the background coincident contribution never exceeds 0.58 %. The 373 keV level is also fed by de-excitation of the 620, 919, 1048, 1171 and probably by the 696 keV levels. Calculations show that the correction to the L/K capture ratio is about 0.05 % and hence negligible.

3.4. M/L CAPTURE RATIOS TO THE 1048, 620 AND 373 keV LEVELS

The M-peaks in the M/L spectra were not completely resolved from the noise because we did not use a coincidence criterion to discriminate against photomultiplier and electronic noise (figs. 2b, 2e and 2h). A computer fitting routine has been used to determine the contents of the M-peak. The noise has been fitted with an exponential function. For the shape of the M-peak we have used a function derived by Prescott from a statistical analysis of the complete scintillation process [11]). As the function in the asymptotic form in his paper is not normalized we give here the proper normalized function:

$$f(x) = \frac{1}{\sqrt{4\pi}} \left(\frac{N}{a}\right)^{\frac{1}{4}} x^{-\frac{3}{4}} \exp\left[2\sqrt{\frac{Nx}{a}} - \frac{x}{a} - N\right].$$

The fitted curves are given in fig. 2 (c, f and i). The results, which are corrected for background coincident contribution, are given in table 1.

3.5. DETERMINATION OF ERRORS

The error can be defined as the standard deviation in the mean of the individual measurements or as the mean of the individual statistical errors. In case of many measurements we used the first definition. When there were few measurements, we used both definitions and accepted the greatest value as error. The statistical uncertainty in the correction for background coincident contribution has been added quadratically to this error. The given errors are statistical and define a 1σ confidence level.

TABLE 1

Experimental M/L capture ratios and maximum correction for background coincident contribution

Level	M/L	Maximum correction
373 keV	0.218 ± 0.006	0.6 %
620 keV	0.217 ± 0.014	4.4 %
1048 keV	0.215 ± 0.009	4.9 %

3.6. DETERMINATION OF $X^{L/K}$, Q_{EC} AND $X^{M/L}$

The Q_{EC} and $X^{L/K}$ values can now be calculated from the experimental L/K capture ratios to the 373 and 1048 keV levels. This is illustrated in fig. 3 in which

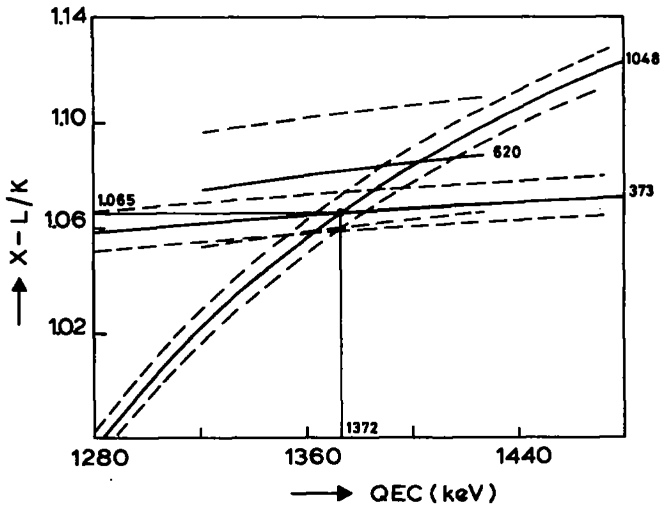

Fig. 3. The $X^{L/K}$ values in dependence on the transition energy Q_{EC} given for the decays to the 373, 620 and 1048 keV levels (solid curves). The broken curves define 1σ error intervals.

$X^{L/K}$ is plotted as a function of Q_{EC} for the measured L/K capture ratios. The Q_{EC} value of the intersection has been determined by equating the reduced L/K capture ratios:

$$\left.\frac{(L/K)}{q_{L_I}^2/q_K^2}\right|_{373} = \left.\frac{(L/K)}{q_{L_I}^2/q_K^2}\right|_{1048}.$$

In this equation q_{L_I} and q_K are the neutrino energies in L_I and K capture respectively. This results in $Q_{EC} = 1372 \pm 16$ keV and $(L/K)/(q_{L_I}^2/q_K^2) = 0.1352 \pm 0.0010$. The value of $X^{L/K}$ has been determined with this Q_{EC} value, resulting in $X^{L/K} = 1.065 \pm 0.008$. The reduced M/L capture ratio $(M/L)/(q_{M_I}^2/q_{L_I}^2)$ and the exchange and overlap correction $X^{M/L}$ have been determined as the mean of the individual values of the three levels resulting in $(M/L)/q_{M_I}^2/q_{L_I}^2) = 0.214 \pm 0.005$ and $X^{M/L} = 1.04 \pm 0.02$.

The experimental reduced L/K and M/L capture ratios have been determined for comparison with theoretical values for respectively

$$\frac{g_{L_I}^2}{g_K^2}\left(1+\frac{f_{L_{II}}^2}{g_{L_I}^2}\right)X^{L/K}, \qquad \frac{g_{M_I}^2}{g_{L_I}^2}\left(\frac{1+f_{M_{II}}^2/g_{M_I}^2}{1+f_{L_{II}}^2/g_{L_I}^2}\right)X^{M/L}.$$

In these expressions g_K, g_{L_I}, g_{M_I}, $f_{L_{II}}$ and $f_{M_{II}}$ are the K, L_I, M_I, L_{II} and M_{II} electron wave functions.

In all these calculations we have used the electron wave functions of Mann and Waber [12]) and the electron binding energies of Bearden and Burr [13]).

4. Discussion

4.1. THE Q_{EC} VALUE

Our Q_{EC} value of 1372 ± 16 keV is somewhat higher than the Wapstra/Gove value of 1340 ± 19 keV [ref. [5])] and the Nuclear Data Sheets value of 1348 ± 7 keV [ref. [3])] but in excellent agreement with the Q_{EC} value of 1372^{+10}_{-20} keV determined by Gehrke *et al.* [6]). The observed decay to the 1342 keV level in ^{131}Cs [ref. [3])] has set a lower limit to the Q_{EC} value of 1348 keV if this decay can proceed via L-capture and of 1378 keV if K-capture would occur. A Q_{EC} value of 1372 ± 16 keV does not exclude this last possibility.

4.2. L/K CAPTURE RATIO TO THE 620 keV LEVEL

Our L/K capture ratio to the 620 keV level lies slightly above the value of Smith and Joshi [4]) as given in table 2. They used also the internal source technique in a coincidence arrangement with a NaI(Tl) γ-detector. Owing to the dimensions of their crystal assembly the chance of partial or complete detection of the 124 keV γ-ray will not be negligible. However, in the measurement coincident with the 496 keV γ-ray they did not correct the K-peak for contributions due to coincident

TABLE 2

Experimental L/K and M/L capture ratios

	This work			Smith/Joshi
	373 keV level	620 keV level	1048 keV level	620 keV level
L/K	0.1438±0.0010	0.149±0.003	0.165±0.001	0.135±0.009
M/L	0.218 ±0.006	0.217±0.014	0.215±0.009	

summation of L X-rays with partially detected 124 keV γ-rays. Thus their L/K capture ratio may be too low.

4.3. EXCHANGE AND OVERLAP CORRECTIONS

Our experimental reduced capture ratios can be compared with the recent calculations by Bambynek *et al.* [2]), see table 3. The use of reduced capture ratios ensures a consistent use of electron wave functions in both the exchange and overlap correction factor and the other part of the expression for capture ratios.

TABLE 3

Experimental reduced L/K and M/L capture ratios in comparison with theory, and also the exchange and overlap corrections $X^{L/K}$ and $X^{M/L}$

	Q_{EC} = 1372±16 keV			Theory [a])	
	373/1048 keV level		620 keV level	Bahcall's approach	Vatai's approach
$\frac{L/K}{q_{L_1}^2/q_K^2}$	0.1352±0.0010		0.137±0.003	0.134	0.132
$X^{L/K}$	1.065 ±0.008		1.08 ±0.02		
	373 keV level	620 keV level	1048 keV level		
$\frac{M/L}{q_{M_1}^2/q_{L_1}^2}$	0.216±0.006	0.214±0.014 0.214±0.005 [b])	0.209±0.009	see fig. 5	see fig. 5
$X^{M/L}$	1.05 ±0.03	1.04 ±0.07 1.04 ±0.02 [b])	1.02 ±0.04		

[a]) Bambynek *et al.* [2]).

[b]) Mean value.

Our reduced L/K capture ratio of 0.1352±0.0010 is in good agreement with the theoretical value of 0.134 calculated by Bambynek *et al.* according to the Bahcall approach and somewhat higher than the value of 0.132 according to the Vatai approach [see also [2]) fig. 4].

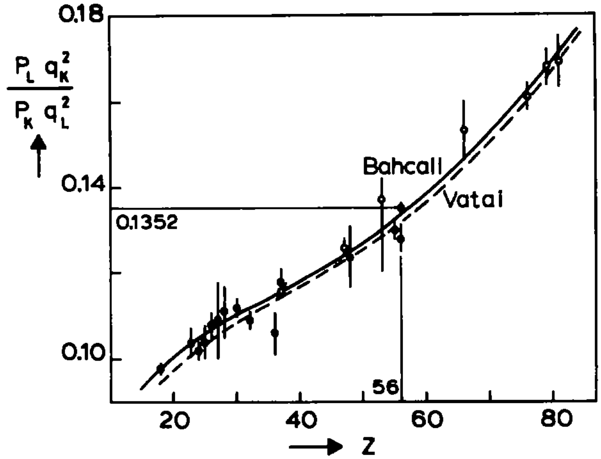

Fig. 4. Comparison of experimentally determined L/K capture ratios for allowed transitions (solid circles) and first-forbidden non-unique transitions (open circles) with theoretical predictions based on wave functions of Mann and Waber and exchange and overlap corrections $X^{L/K}$ according to Bahcall's approach (solid curve) and Vatai's approach (broken curve) [2]).

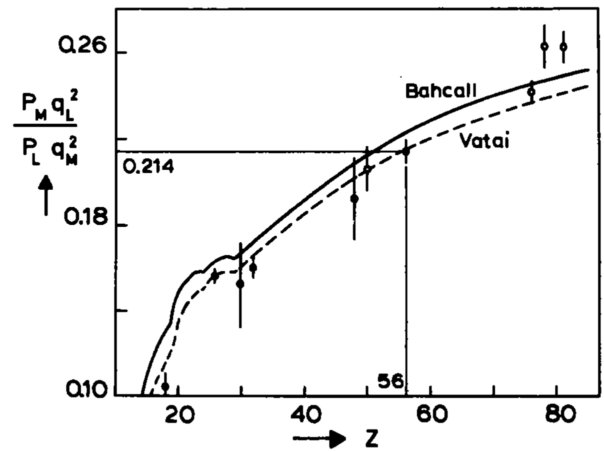

Fig. 5. Comparison of experimentally determined M/L capture ratios for allowed transitions (solid circles) and first-forbidden non-unique transitions (open circles) with theoretical predictions based on wave functions of Mann and Waber and exchange and overlap corrections $X^{M/L}$ according to Bahcall's approach (solid curve) and Vatai's approach (broken curve) [2]).

Fig. 5 [ref. [2])] shows that our reduced M/L capture ratio of 0.214 ± 0.005 is in excellent agreement with the Vatai curve and somewhat lower than the Bahcall curve.

In addition, our $X^{L/K}$ value does not support the idea stated by Goverse, that correlation effects would result in systematic discrepancies between experimental and theoretical exchange and overlap corrections for L/K capture ratios.

References

1) S. C. Goverse and J. Blok, Phys. Lett. **50A** (1974) 135
2) W. Bambynek, H. Behrens, M. H. Chen, B. Crasemann, M. L. Fitzpatrick, K. W. D. Ledingham, H. Genz, M. Mutterer and R. L. Intemann, Rev. Mod. Phys. **49** (1977) 77
3) R. L. Auble, H. R. Hiddleston and C. P. Browne, Nucl. Data Sheets **17** (1976) 573
4) K. M. Smith and B. R. Joshi, Proc. Phys. Soc. **82** (1963) 918
5) A. H. Wapstra and N. B. Gove, Nucl. Data Tables **9**, nos. 4, 5 (1971)
6) R. J. Gehrke, R. G. Helmer, C. W. Reich, R. C. Greenwood and R. A. Anderl, Phys. Rev. **C14** (1976) 1896
7) W. Goedbloed, S. C. Goverse, C. P. Gerner, A. Brinkman and J. Blok, Nucl. Instr. **88** (1970) 197
8) S. C. Goverse, J. van Pelt, J. van den Berg, J. C. Klein and J. Blok, Nucl. Phys. **A201** (1973) 326
9) S. C. Goverse, J. Kuijper and J. Blok, Z. Phys. **269** (1974) 111
10) S. C. Goverse, J. C. Klein, J. Kuijper and J. Blok, Nucl. Phys. **A227** (1974) 506
11) J. R. Prescott, Nucl. Instr. **22** (1963) 256
12) J. B. Mann and J. T. Waber, Atomic Data **5** (1973) 201
13) J. A. Bearden and A. F. Burr, Rev. Mod. Phys. **39** (1967) 125