FIZIKA 5 (1973) 195-202

THE L- AND M-SUBSHELL CONVERSION RELATIVE INTENSITIES FOR 100 keV TRANSITION IN ^{182}W

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Received 30 September 1972; revised manuscript received 20 september 1973

Abstract: A careful measurement of L- and M-electron conversion relative intensities in the 100 keV deexcitation of ^{182}W has been performed by means of a reconstructed iron-free double focussing beta-ray spectrometer. The results of individual L- and L/M-conversion ratios as well as earlier reported experimental values for some other pure E2 transition for deformed nuclei in the rare earth region are compared with theoretical values by Hager and Seltzer and Pauli. This is done in order to reinvestigate the possibility of earlier reported discrepancies with theory for some of the above conversion ratios.

1. Introduction

The 100.09 keV 2^+ state of ^{182}W decays through pure E2 transition to the ground 0^+ state. Fig. 1 shows a part of the measured spectra.

In the region of deformed nuclei there is strong low-energy 2^+-0^+ transition and measurements of the L- and M- subshell ratios for some of those pure E2 transitions have been made at different iron-free double focussing beta-ray spectrometers by several groups referred to in Ref.$^{3)}$.

The result obtained by S. E. Karlsson et al.$^{3)}$ for L_I/L_{II} and L_I/L_{II} ratios for four 2^+-0^+ transitions (86.79 keV in ^{160}Dy, 80.57 keV in ^{166}Er, 84.26 keV in ^{170}Yb and 100.09 keV in ^{182}W) is that the experimental values are 5–9% higher than the mean theoretical values calculated from the tabulations by Rose$^{4)}$ and Sliv and Band$^{5)}$.

The discrepancies for L_I/L_{II} and L_I/L_{III} ratios have been supported also by other measurements [1,2], and a deviation between experiment and theory of 6% for L_I/L_{II} and L_I/L_{III} ratios can be regarded as true. This has been correlated[6] with the well agreement from different theoretical calculations [4,5,7,8]. However it has been known that the tabulations of Rose[4] and Sliv and Band[5] differ in their respective treatment for penetration effects as outlined in Ref.[9].

We found it useful to do more investigations about the discrepancies mentioned above, as to review earlier reported experimental results for measured L and L/M conversion intensity ratios for some pure E2 transitions, and compare them with theory (recent tabulations of Hager and Seltzer[9] and from Pauli's computer program[11] whenever both those theoretical calculations come to be in agreement. This will make any deviations rather more confirmed whenever both those theoretical calculations come to be in agreement. The reported measured values with a rather good precision may offer a versatile tool for testing theory[8,11], by which the absolute values of M conversion coefficients are also carefully elaborated.

We found it important to do the measurement of L- and L/M ratios as careful as possible by means of our reconstructed iron-free beta-ray spectrometer described elsewhere[14]. Since this nucleus is placed at the end of deformed region A = 150 — — 185 it could be useful for the purpose of further investigations (see discussion).

2. *Source and detector*

The ^{182}Ta activity was irradiated for 28 days in the Swedish R2 reactor in a flux of about 2.10^{14} neutrons/(cm^2 · s) The target material was a »specpure« tantalum metal. The inactive material was desposited onto an aluminium foil of thickness

Table 1
Relative intensities of 100 keV conversion line.

Transmition energy (keV)	Conversion shell	Relative conversion line intensity	
		Nilsson et al.[16]	Present work
100.09:	L_I	939	957±50*
	L_{II}	10850	10819±130
	L_{III}	10000	10000± 70
	M_I	285	193± 60
	M_{II}	2613	2925± 70
	M_{III}	2375	2703± 60
	$M_{IV,V}$	47	< 65

*The limits of our errors are twice the errors in the weighted average values.

0.7 mg./cm^2 using a cathodic sputtering technique. The source strip of 0.5 × 20 mm^2 dimension was used. The cut-off energy of the GM-tube was not sufficiently low to ensure 100% transmission for energies at which our measurements were taken. Correction for absorption in the GM window has been estimated by means of a reproduced transmission curve for 2.0 mg/cm^2 mica window (Ref.[10]) on an enlarged scale. It was not necessary to correct for the counter dead time.

3. Measurement and analysis

The internal conversion spectrum of the 100 keV transition in ^{182}W was investigated using the source described above. A scanning was performed by means of a 50 cm radius iron-free double focussing beta-ray spectrometer[14],which is operated manually. The baffle of the spectrometer and the slit of GM-tube as well as the source width geometry were set to yield a resolution of 0.08% in case where a thin source[14] is available. The resolution in measurement due to a rather thick source was found to be 0.17%.

A scanning was performed after the tantalum source was left to decay for at least six months to provide a basis for a determination of ^{182}Ta activity only. The source becomes rather weak, and a total of 11 runs were then concentrated on the L- and M- subgroups and a few times arround the N internal conversion line in order to define the beta background well. This rather weak source required long measuring periods of 72 hours for each complete run in order to obtain good statistics. Correction for the decay has been performed using the ICL-1905E computer.

A care was taken to ensure a good current control in the spectrometer during the time for each measured point and the compensation of all components of external magnetic fields were checked inside the spectrometer before and after recording both L- and M- lines separately.

We have learned about the thickness of our radioactive source from the experimentally measured spectrum and resolution value difference in recorded line profile. As a result we thought it could be of some advantage to achieve a good method of analyzing our data. This has been done by means of a computer program* compiled for the analysis of an electron momentum spectrum. The program was carried out by ICL-1905E computer (Cairo Univ.) and was employed as outlined in Ref.[15]. The L_{III} line shape was used for separation of the L_I from the L_{II} and such process was extended for the M-region analysis.

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*«EGLAD» computer program was put at our disposal by EDC-group, Institute of Physics, Uppsala, Sweden.

The tails of the $L_{..}$ and $L_{...}$ lines appear under the $L_{,}$ line and iterative method used (using the computer program) in order to adjust a preliminary chosen lineshape. Each time the lineshape was modified by using the deviations between the measured curve and the fitted one. The natural background (75 c/100s) was subtracted, and the underlying beta background is approximated by a horizontal straight line in our energy region of interest. Finally a good fit was achieved, and an example of such process of analysis of the electron spectrum is shown in Fig. 1 and the numerical weighted average intensity values are given in Table 1, where also the results of Nilsson et al.[16] are quoted for comparison.

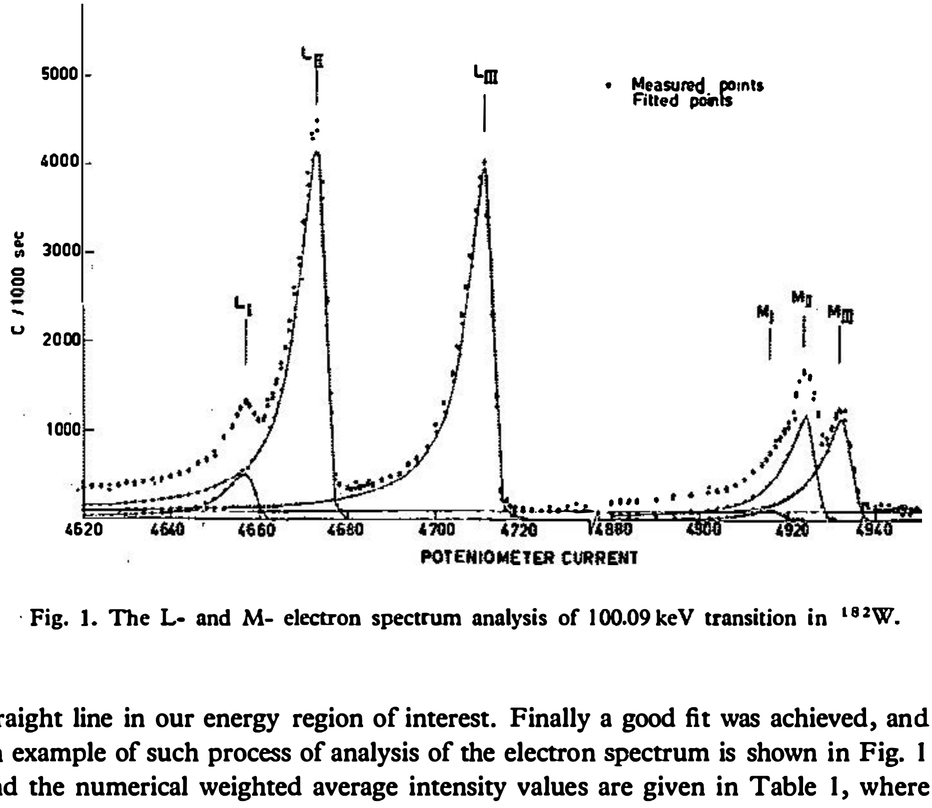

Fig. 1. The L- and M- electron spectrum analysis of 100.09 keV transition in ^{182}W.

4. *Results and discusssion*

The influence on the internal conversion coefficient (ICC) due to the finite extension of the nucleus, so-called »static« effect, and its internal structure, »penetration« effect, has been shown in detail by Church and Weneser[17]. However, Hager and Seltzer[8] and Pauli [11] have more recently given theoretical absolute ICC, where both of these nuclear effects are treated. In addition, they also introduce other several significant improvements in the calculations. We have used for our ICC calculations Pauli computer program[11], for which the atomic binding energies are from Ref. [18] and screening functions are taken from Ref. [12]. The ICC for a shell or a subshell σ, for E2 electric transition is defined[9] as the product of static part a (σ, E2) which corresponds to Rose tabulations and anomaly factor $\Delta(\sigma$, E2) contain all penetration effects.

The calculations have been carried out by means of ICL-1905E computer (Cairo Univ.). The anomaly factor for supposed pure E2 transition is substituted by unity, and the calculated E2 L and L/M shell ratios are listed in Table 2, where $2^+ - 0^+$ deformed states in some of the rare-earth nuclei are considered.

Similarly, Hager and Seltzer, define ICC as the product of a (σ, E2) as tabulated in Ref.[8] and penetration terms Ref.[19]. The tabulated a (σ, E2) could be understood to substitute those values of Sliv and Band[5]. For cases of our interest in Table 2 the values are produced using a specially constructed computer program for an energy interpolation.

The extensive experimental results listed in Table 2 are inspected with emphasis on those measured values which have precision (1—3%). Those are included in measurements denoted by a), b) and c). Also the theoretical values of indicated shell ratios obtained from calculations [8, 11] are presented. Comparisons between theory [8, 11] and those experimental values of L subshell ratios, specially those with high precision, show that deviations of L subshell ratios from theory of Hager and Seltzer are regularly less pronounced than deviations from Pauli's theory[11]. This slight discrepancy may still appear due to approximations in both theoretical calculations. However, the deviations between both of those theoretical predictions [8, 11] for the indicated subshell ratios are not significant. Their assigned limits of errors (2—3%) for the L subshell ratios make it rather evident. As a result, the 5—6% anomaly earlier reported for low energy pure E2; $L_I : L_{II}$ and $L_I : L_{III}$ subshell ratios seem to be possible even in the light of recent theoretical calculations.

On the other hand, when such comparisons with theory for all reviewed experimental results in Table 2 are investigated as a whole, it is found that $L_I : L_{III}$ ratios agree with theory while an anomaly can be seen in the $L_I : L_{II}$ and $L_I : L_{III}$ ratios. Since the deviations are not statistically distributed, it means that the anomaly is real and has a value 5—6% (concerning high precision measurements) higher than theoretical prediction.

The result obtained from our investigation for L subshell ratios Table 2 could be considered as the fourth confirmation for the existence of the anomaly of the intensity ratio where L_I electrons are involved. We have also our experimental value for L/M ratio (3.74±0.15) for the 100 keV transition in ^{182}W, which is produced by summing the individual intensities of L-and M-lines. A value of L/M ratio (4.09 ± 0.03) is similarly produced by Nilsson et al. [16], and also another value, by him for $\Sigma L/\Sigma M$ (3.80), obtained from measurement which is referred in Ref.[6]. The comparison of the L/M ratio produced as an average value (3.88) with

TABLE 2

Compilation of indicated subshell conversion ratios and a comparison with theory for some pure E2 transitions

Istope and E (in keV)	Experimental ratios				Theoretical ratios				EXP./THEORY.			
	$L_I : L_I$	$L_I : L_{III}$	$L_{II} : L_{III}$	$L_{III} : M_{III}$	$L_I : L_{II}$	$L_I : L_{III}$	$L_{II} : L_{III}$	$L_{III} : M_{III}$	$L_I : L_{II}$	$L_I : L_{III}$	$L_{II} : L_{III}$	$L_{III} : M_{III}$
$^{166}_{66}$Dy 86.70	0.1350 ± 0.0034	0.1309 ± 0.0038	0.968 ± a) 0.008		0.131 0.127	0.127 0.123	0.968 0.972	4.158+) 3.903++)	1.033 1.085	1.03 1.06	1.000**) 0.996	
		0.1300 ± 0.003	0.953 ± b) 0.007							1.02 1.06	0.981 0.995	
		0.1300 ± 0.002	0.967 ± c) 0.014							1.02 1.06	0.999 0.995	
^{166}Er 80.57	0.0910 ± 0.0015	0.0871 ± 0.0038	0.959 ± a) 0.005	4.00 ± e) 0.05	0.0863 0.0828	0.0838 0.0805	0.972 0.973	4.105 4.076	1.050 1.100	1.04 1.08	0.987 0.986	0.974 0.981
		0.0872 ± 0.0020	0.962 ± b) 0.010	4.37 ± f) 0.12						1.04 1.08	0.990 0.989	1.065 1.072
		0.0859 ± 0.0015	0.944 ± c) 0.014							1.03 1.07	0.971 0.970	
	0.104 ± 0.011	0.1020 ± 0.0110	0.978 ±d) 0.015						1.210 1.260	1,22 1.27	1.006 1.005	
^{170}Yb 84.26	0.0829 ± 0.0020	0.0817 ± 0.0032	0.985 ± a) 0.008	3.91 ± e) 0.04	0.0779 0,0753	0.0786 0.0760	1.009 1.010	4.051 4.016	1.06 1.10	1.04 1.08	0.976 0.975	0.965 0.974
		0.0799 ± 0.0018	0.994 ± b) 0.010							1.02 1,05	0.985 0.984	
		0.0810 ± 0.0012	0.996 ± c) 0.014							1.03 1.07	0.987 0.986	
	0.089 ± 0.008	0.0888 ± 0.0070	1.000 ± d) 0.029						1.14 1.18	1,13 1.17	0.991 0.990	
	0.093 ± 0.010	0.0950 ± 0.0100	1.020 ± h) 0.020						1.19 1.24	1.21 1,25	1.011 1.010	
^{176}Hf 88.30	0.0840 ± 0.0090	0.0870 ± 0.0090	1.040 ± h) 0.020		0.0719 0.0698	0.0754 0.0733	1.049 1.050	3.988 3.967	1.17 1.20	1.15 1.19	0.991 0.990	
^{182}W 100.09	0.0866 ± 0.0041	0.0939 ± 0.0043	1.085 ± a) 0.016	3.72 ± e) 0.07	0.0787 0.0805	0.0882 0.0803	1.120 1.123	3.950 3.834	1.10 1.08	1.06 1.04	0.969 0.966	0.942 0.960
	0.1010 ± 0.0100	0.1120 ± 0.0110	1.110 ± g) 0.020						1.28 1.26	1,27 1.24	0.991 0.988	
	0.1180 ± 0.0160	0.1270 ± 0.0160	1.072 ± h) 0.021						1.50 1.47	1.44 1.41	0.957 0.955	
	0.0885 ± 0.0047	0.0957 ± 0.0050	1.082 ± 0.015	3.70 ± *) 0.09					1.12 1.10	1.09 1.06	0.966 0.963	0.937 0.965

a) Ref.[3] (and all proceded values), b) Ref.[20], c) Ref.[1], d) Ref.[13], e) Ref[6], f) Ref[23], g) Ref[21], a) Ref[22].
*) Present work. **) Each experimental value has two values compared with theory; the upper due to +) and the lower due to ++).
+) Theoretical values due to Hager and Seltzer[8]).

++) Theoretical values due to Pauli[11]).

corresponding theoretical predictions 3.98 due to Hager and Seltzer$^{8)}$ and 3.87 due to Pauli$^{11)}$ probably shows that the absolute values of the M conversion coefficients due to Pauli are less uncertain.

The use of a computer program for unfolding our spectrum Fig. 1, has made possible to determine L,,,/M,,, intensity ratio with rather small error. The value is in good agreement with that earlier reported by Nilsson et al.$^{6)}$ which means that deviations of the L,,,/M,,, (as could be seen in Table 2) from theoretical predictions seem to be real with the increase of energy and/or atomic number.

As far as it is seen from Table 2 the deviations of L,/L,, and L,/L,,, subshell ratios from theory are significant. The reason for this could be understood in the light of what is called a »higher-order corrections to internal conversion« by Hager and Seltzer$^{24)}$, where the theoretical predictions of L,/L,, for both ^{182}W and ^{160}Dy are expected to be of 5—6% higher.

Also in another recent investigation Band et al.$^{25)}$ showed that the inner part of the atoms is of major importance for the internal conversion coefficients. It is suggested that this may offer an explanation for the anomalies in the ratios where L, electrons are involved.

Acknowledgement

The authors have the pleasure to express their sincere gratitude to Dr. Ö. Nilsson, Institute of Physics, Uppsala, for his generous support, stimulating discussions and valuable comments during the course of this work.

We are also indebted to Prof. A. Youssef, the head of physics department for his kind interest in the work.

Thanks are also due to Assist. Prof. O. Bergman, the Director of International Seminar of Physics at Uppsala for the fruitful cooperation.

Sending the FORTRAN deck of Pauli computer program by EDC-group (from the same Institute) is highly appreciated.

References

1) P. Erman, G. T. Emery and M. L. Perlman, Phys. Rev. **147** (1966) 858;
2) W. Gelletly, J. S. Geiger and R. L. Graham, Phys. Rev. **157** (1967) 1043;
3) S-E. Karlsson et al., Nucl. Phys. **89** (1966) 513;
4) M. E. Rose, Internal Conversion Coefficinets (North-Holland Publ. Co., Amsterdam, 1958);
5) L. A. Sliv and I. M. Band, in Alpha-Beta. and Gamma-Ray Spectroscopy, ed. K. Siegbhahn (North-Holland) Publ. Co., Amsterdam, 1965;
6) Ö. Nilsson, I. Thoren, G. Malmsten and S. Hogberg, Nucl. Phys. **A120** (1968) 561;
7) C. P. Bhalla, Phys. Rev. **157** Q1967) 1136;
8) R. S. Hager and E. C. Seltzer, Nucl. Data **A4**, 1 (1968); CALT-63-60 Research and Development Report (1967);

9) H. C. Pauli, COO-1420-136 (1967),
H. C. Pauli, Helv. Phys. Acta **40** (1967);
10) O. Huber, F. Humbel, H. Schneider and A. De Shalit, Helv. Phys. Acta, **25** (1952) 3;
11) H. C. Pauli, A Computer Program for Internal Conversion Coefficient and Particle Parameters (Priv. Comm.), 1970;
12) F. Herman and S. Skliman, Atomic Structure Calculations (1963) Prentice-Hall Inc., Englewood Clifts, Newgersey);
13) E. Bashandy and M. Migahed, Zeitschr. für Physik **195** (1966) 435;
14) Ö. Nilsson et al., Int. Report **121** (1971) AEE, ARE;
15) L. Samuelsson, R. Vukanović, M. Mighaed, M. Zupančić, L. O. Edvardson and L. Westerberg, Nucl. Phys. **A135** (1969) 663;
15) Ö. Nilsson S. Hogberg, S-E. Karlsson and G. H. El-Sayed, Nucl. Phys. **A100** (1967) 351;
17) E. L. Chérch and J. Weneser, Phys. Rev. **104** (1956) 1382;
Ann. Rev. Nuclear Sci. **10** (1960) 193;
18) C. M. Ledarer, J. M. Hollander and I. Perlman, Table of Isotopes, *6th* ed. p. 566 (J. Wiley and Sons, New York 1967);
19) R. S. Hager and E. A. Seltzer, Nuclear Data **A6** (1969);
20) W. Gelletly, J. S. Geiger and R. L. Graham, Bull. Am. Phys. Soc. **11** (1966) 352;
21) R. Stepić, M. Bogdanović, and M. Mladenović, Proceedings of the international conference on the internal conversion Process, B 507, May 10—13, 1965, Vanderbilt University, Nashville, Tennessee;
22) W. H. Brantley, S. C. Panoholi and J. H. Hamilton, Nucl. Phys. **83** (1966) 545;
23) M. Arnoux and A. Gizon, Compt. Rend. **264** (1967) 1518;
24) R. S. Hager and E. C. Seltzer, Phys. Rev. *C*2 (1970) 902;
25) I. M. Band, L. A. Sliv and M. B. Trzhaskvskaya, Formation Region of Internal Conversion Coefficients (Academy of Sciences of the USSR, A. F. Ioffe Physico-Technical Institute Leningrad, 1970);
26) P. Galan and M. Vejs, Fyzikalny Časopis, SAV **22** (1972) 60.