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EFFECT OF FINITE NUCLEAR SIZE ON THE RELATIVE INTERNAL CONVERSION COEFFICIENTS IN L SUBSHELLS*

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The relative conversion coefficients in L subshells have been measured for three pure M1 transitions: 46.5 kev in Bi^{210} and 115.1 and 238.6 kev in B^{212}. It is shown that in order to obtain agreement with experimental data the finite nuclear size must be taken into account in theoretical calculations of the L-conversion coefficients. The ratios $L_I:L_{II}:L_{III}$ for the M1 transition of 277.3 kev in Pb^{208} have also been measured.

1. INTRODUCTION

In several experimental papers[1-6] it has been established that the K-conversion coefficients found experimentally for heavy nuclei for M1 transitions turned out to be appreciably lower than the theoretical coefficients calculated by Rose[7] for a point nucleus. This difference agrees approximately with the correction ($\sim 30\%$) for finite nuclear size proposed by Sliv.[8] It has been shown both theoretically[9] and experimentally[1,4,10] that approximately the same correction should be applied also to the L_I-conversion coefficients. At the present time it may be considered as established that it is necessary to take into account the finite nuclear size in making theoretical calculations of internal conversion coefficients for the K and L_I shells in the case of M1 transitions.

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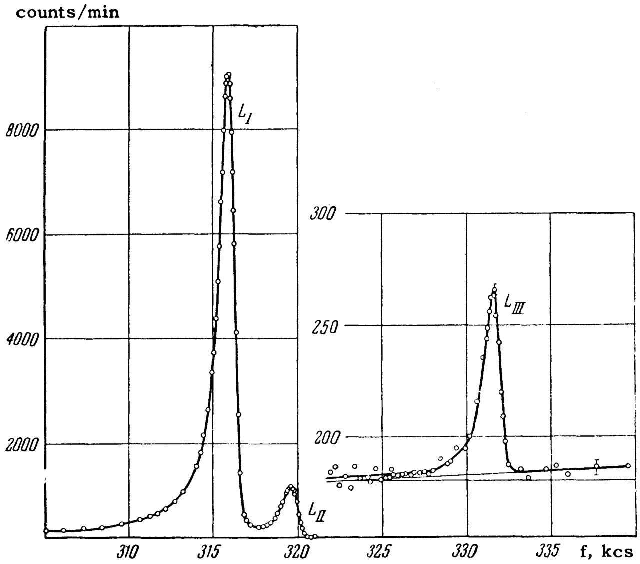

FIG. 1. L_I, L_{II} and L_{III} conversion lines for the 46.5-kev transition in Bi^{210}. In this graph and in subsequent graphs the proton resonance frequency f which is proportional to $H\rho$ has been plotted along the horizontal axis. $\Delta H\rho/H\rho$ is equal to 0.37% for L_I and to 0.35% for L_{III}.

With respect to the effect of the finite nuclear size on the conversion in the L_{II} shell the available experimental data[1,4,10,11] are of a contradictory character, owing to the low accuracy of measurement. Recently Band and Sliv have carried out calculations of conversion coefficients for the L_I, L_{II}, and L_{III} subshells. Preliminary results of these calculations, kindly communicated to us by the authors, show that the effect of finite nuclear size is significantly different for the different L subshells. The correction does not depend strongly on the energy, and for $Z = 83$ amounts to $\sim 33\%$ for the L_I subshell, to 11% for the L_{II} subshell, and is small in the case of the L_{III} subshell. Therefore, the ratios $L_I : L_{II} : L_{III}$ should be sensitive to nuclear size.

The object of the present work consists of the experimental investigation of the effect of finite nuclear size on the relative conversion coefficients in the L subshells for M1 transitions. The following points are significant in such an investigation: (1) the accuracy in the determination of the relative intensities $L_I : L_{II} : L_{III}$ should be not less than 5%; (2) it is necessary to be certain that the lines being studied are pure M1 transitions, for even a small admixture of E2 may strongly affect the ratio $L_I : L_{II} : L_{III}$.

2. EXPERIMENTAL DATA

Internal conversion in L-subshells was studied in the case of the following three M1-transitions: the 46.5-kev transition occurring in the decay $RaD \xrightarrow{\beta} RaE\ ({}_{83}Bi^{210})$ and the 115.1 and 238.6-kev transitions occurring in the decay $ThB \xrightarrow{\beta} ThC\ ({}_{83}Bi^{212})$. According to Krisiuk et al.,[12] all three transitions take place between levels with spins 0^- and 1^-, and are therefore pure M1 transitions.

The work has been carried out using a magnetic spectrometer of the ketron[13] type. The measurement and the stabilization of the magnetic field was carried out by means of the proton magnetic-resonance method.[14] Electrons were recorded by means of Geiger-Müller counters. The resolving power of the apparatus was varied from 0.05 to 0.36%, and was chosen for each line in such a way as to give a complete resolution of the lines with the maximum possible aperture. Figures 1 and 2 show several sets of measurements of the lines described above. The 115.1-kev transition is a fairly weak one, and therefore the ratio $L_I : L_{II}$ for it was measured with a resolving power of 0.14%, while the ratio $L_I : L_{III}$ was measured with a resolving power of 0.23% (Fig. 2); the L_{III} line for this transition had not been observed previously.

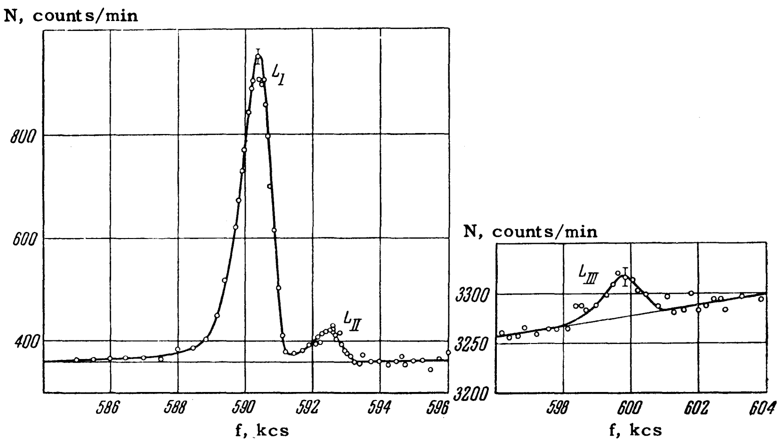

FIG. 2. L_I, L_{II} and L_{III} conversion lines for the 115.1 kev transition in Bi^{212}. The L_{III} line has been measured with a resolution of 0.23%. $\Delta H\rho/H\rho$ = 0.14% for L_I.

TABLE I

Decay	E_γ, kev	$L_I : L_{II} : L_{III}$
RaD → RaE (Bi^{210})	46.5	100 : (10.6 ± 0.2): (0.93 ± 0.05)
ThB → ThC (Bi^{212})	115.1	100 : (10.4 ± 0.3): (0.88 ± 0.10)
ThB → ThC (Bi^{212})	238.6	100 : (10.4 ± 0.2): (0.74 ± 0.05)

TABLE II

Transition	$L_I : L_{II} : L_{III}$	Reference
46.5 kev	100 : (10.2 ± 0.7) : (0.95 ± 0.05) *	
	100 : (10.5 ± 0.4) : (1.0 ± 0.1)	[16]
238.6 kev	100 : (10.8 ± 0.1) : (0.80 ± 0.02)	[17]
	100 : (11.6 ± 0.3) : (0.66 ± 0.04)	[11]
	100 : (10.0 ± 0.7)	[10]

*These results have been obtained by A. A. Bashilov, B. S. Dzhelepov, and L. S. Chervinskaia in 1955 and have been communicated to us privately by the authors.

We determined the ratio $L_I : L_{II} : L_{III}$ directly from the heights of the corresponding lines. In addition to the correction for the decay, the following corrections were introduced during the reduction of the experimental data: (1) a correction for the magnitude of the "tail" of the L_{II} line under the L_I-line, which amounted to 1 or 2%; (2) for the 46.5-kev transition a correction was made, in addition to the above, for the variation in the half-width of the line with variation of H_ρ. Such a dependence of the half-width on H_ρ is explained, in the case of our apparatus, by the distortion of the topography of the field for $H_\rho <$ 1000 Oe-cm, and we have studied it by recording the conversion spectrum of an active radiothorium deposit.[15] The correction amounts to 1.2% for the ratio $L_I : L_{II}$ and to 6.5% for the ratio $L_I : L_{III}$.

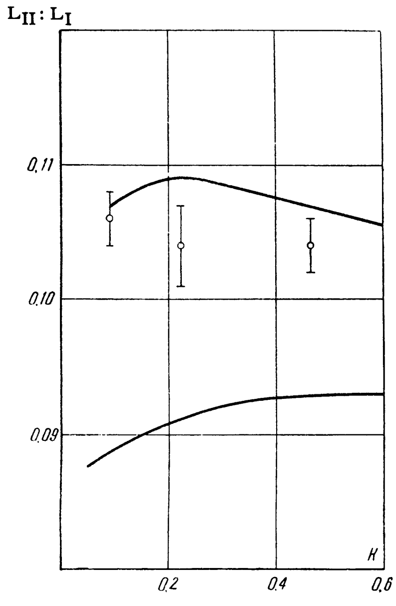

FIG. 3. Comparison of theoretical and experimental values of the ration $L_{II} : L_I$. K is the γ-ray energy in units of m_0c^2.

No corrections were made for absorption in counter windows, and for missed counts; under our conditions they were both small (< 1%).

Four to five sets of measurements were taken for each line. Table I gives averaged results. The errors shown in the table are somewhat larger than statistical, because the possible presence of systematic errors was taken into account.

For comparison with our results, we give in Table II values of relative conversion coefficients in L subshells for the 46.5 and 238.6 kev transitions taken from references 10, 11, 16, and 17, carried out since 1955. The results of earlier work are subject to considerable experimental error and are not given in the table. It can be seen from the table that for both transitions our results agree within experimental error with the results of the other papers, except for the ratio $L_I : L_{II}$ given by Krisiuk et al.[11] which gives a discrepancy of ~ 10%. In this work carried out in our laboratory the errors shown in the table are purely statistical ones, and do not include a systematic error which was discovered by us later. The introduction of an appropriate correction leads to agreement between the results.

It should be noted that in the paper by Bashilov et al.[18] a 31.9-kev line of intensity comparable to the L_{III} line was found between the L_{II} and L_{III} lines in the course of obtaining the conversion spectrum of RaD. As can be seen from Fig. 1, we do not have such a line in this region.

3. COMPARISON WITH THEORY

In order to compare the experimental results with the theoretical ones we have plotted in the graphs of Figs. 3 and 4 the theoretical ratios

$L_{II} : L_I$ and $L_{III} : L_I$ as functions of the energy. We have also given there the corresponding experimental ratios. The lower curves in both graphs have been plotted according to the tables of Dranitsyna[19] who interpolated Rose's results[7] with respect to Z and energy. The upper curves have been plotted according to the tables of Band and Sliv. The accuracy of the theoretical values communicated to us by Band and Sliv amounts to $\sim 2\%$.

It may be seen from Figs. 3 and 4 that within experimental error the calculations of Band and Sliv, carried out taking finite nuclear size into account, agree well with the experimental results. Rose's calculations for a point nucleus disagree noticeably with the experimental results. Thus from our data it follows that the finite nuclear size makes an appreciable contribution to the relative L-conversion coefficients, and that this contribution has been correctly taken into account in the calculations of Band and Sliv.

In all three cases of γ transitions studied by us, as has been shown by Krisiuk et al.,[12] apparently a transition of one neutron takes place from the $g_{9/2}$ state to the $i_{11/2}$ state, i.e., the transitions are l-forbidden. In all cases when the lifetimes of l-forbidden M1-transitions were measured, a retardation by 2 or 3 orders of magnitude was found. All these transitions take place in odd nuclei. If a similar retardation takes place in the transitions investigated by us in odd-odd nuclei, we can expect to observe the influence of nuclear structure on the relative conversion coefficients for the M1-transitions, which was noted by Church and Weneser.[20] The good agreement between our results and Sliv's calculations indicates that even if nuclear structure does affect the ratio $L_I : L_{II} : L_{III}$ in the M1 transitions studied by us, this effect must be less than 5%.

4. RELATIVE CONVERSION COEFFICIENTS FOR THE 277.3-kev TRANSITION IN Pb^{208}

In addition to the pure M1 transitions discussed above, we have also measured the ratio $L_I : L_{II} : L_{III}$ for the 277.3-kev M1 transition between two excited levels of Pb^{208}, 3474.8 kev (4^-) and 3197.5 kev

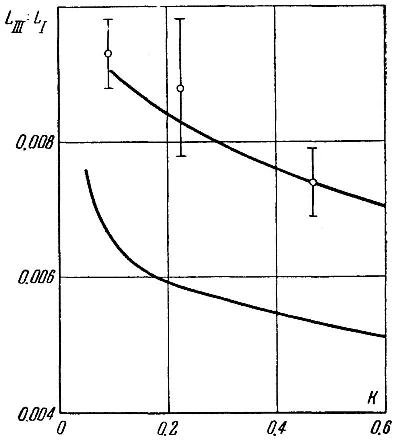

FIG. 4. Comparison of theoretical and experimental values of the ratio $L_{III} : L_I$.

(5^-). An admixture of E2 radiation is possible in this transition.

We determined the ratio $L_I : L_{II}$ for this transition with a resolution of 0.05%, and the ratio $L_I : L_{III}$ with a resolution of 0.23%.

The average value of the ratio $L_I : L_{II} : L_{III}$ obtained from 4 or 5 sets of measurements is given in Table III. Moreover, in this table we have also given the value of $K : L_I$ which has been calculated from the ratio $K : (L_I + L_{II})$ found in our laboratory.[21] From the table it may be seen that the value of the ratio $L_I : L_{II} : L_{III}$ for this transition differs appreciably from the corresponding ratios for the pure M1 transitions (cf. Table I). This difference may be easily explained by the existence of a small admixture of E2 radiation in the 277.3-kev transition. In Table III we have shown the values of the admixtures of E2 obtained by using both the new conversion coefficients of Band and Sliv, and also Rose's coefficients.[7] When Sliv's coefficients are used, good agreement is found between the values of admixtures of E2 obtained from the two independent ratios $L_I : L_{II}$ and $L_I : L_{III}$.

The amount of admixture of E2 radiation in the 277.3-kev transition is $\sim 5\%$. Thus it can be seen that with a sufficient precision of measurement the use of the new conversion coefficients allows us to determine the admixture of E2 radiation even in the case when this admixture amounts to only a few percent of the main radiation. Such small admixtures were previously determined primarily from measurements of angular correlation.

TABLE III

E_γ, kev	$K:L_I$	$L_I : L_{II} : L_{III}$	Admixture of E2, percent			
			$L_I : L_{II}$	$L_I : L_{III}$	$L_I : L_{II}$	$L_I : L_{III}$
			According to Sliv		According to Rose	
277.3	6.15±0.3	100 : (12.5±0.6) : (1.9±0.3)	4.8±1.5	5.2±1.4	11.0±1.5	8.8±1.8

If the probability of γ transitions is assumed to be correctly described by Moszkowski's formula,[22] then the ratio E2 : M1 for the 277.3-kev transition turns out to be equal to $\sim 10^{-4}$. However, the results of our measurements show that this ratio is equal to 0.05. The existence of an appreciable admixture of E2 radiation may be due to a retardation of the M1 transition.

The retardation of the M1 radiation in this case is not explained by the structure of the excited levels of Pb^{208}, proposed by Tauber.[23] According to Tauber the 277.3-kev transition takes place between levels of the same multiplet. The probability of such a transition must agree with the single-particle estimate. This has been confirmed experimentally in the case of the 40-kev M1 transition in Tl^{208}. This transition takes place between the multiplet levels $s_{1/2}\, g_{9/2}$ and direct experimental measurements of the lifetime[24] agree with calculations according to the shell model.[25] Moreover, the ratio $L_I : L_{II} : L_{III}$ for this transition[26] does not allow an admixture of E2 radiation in excess of 0.05%. It is also difficult to expect an appreciable retardation of the M1 transition in the case of transitions between levels of any other multiplet. Therefore the occurrence of an appreciable admixture of E2 radiation in the 277.3-kev transition in Pb^{208} does not agree with Tauber's assumption[23] that the initial and the final levels of this transition belong to the same multiplet.

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