ON THE NATURE OF HIGHLY EXCITED LEVELS IN W^{182}

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The nature of hard γ quanta from W^{182} is studied by measuring internal conversion in β decay of Ta^{182}. The experimental ratios of the reduced probabilities are compared with the predictions of various theoretical nuclear models.

INTRODUCTION

THE even-even nucleus W^{182} is in the deformed-nuclei region. The complex level scheme of W^{182} was first constructed by Murray et al [1] from a parallel study of the β spectrum and the conversion-electron spectrum with a β-spectrometer and of the γ-ray spectrum with a bent-crystal spectrometer. Some of these conclusions were confirmed by measurements of the angular $\gamma\gamma$ correlation [2] and measurements of the coincidences [3] for Ta^{182} decay.

At the present time the main features of the W^{182} level scheme have been sufficiently well established. There are still, however, some unanswered questions, both theoretical and experimental. In the present work we investigated further the nature of the W^{182} γ transition in the high-energy region by measuring internal conversion in β decay of Ta^{182}.

To check on the predictions of the various theoretical models as applied to this nucleus, we calculated the ratios of the reduced probabilities.

EXPERIMENT AND MEASUREMENT RESULTS

The measurements were carried out with a β spectrometer with double focusing at an angle $\pi\sqrt{2}$. The resolution of the β spectrometer, determined from the K lines of the 411.8-keV radiation of Hg^{198}, was 0.2% [4].

The source used was tantalum oxide dissolved in amyl acetate. The sources were deposited on an aluminum substrate $5\,\mu$ thick. We used sources 3.6 and 1 mg/cm^2 thick to investigate the conversion spectrum in the energy regions 800—1000 and 1000—1300 keV, respectively. The compound was obtained by bombarding the source with a neutron current of $1.8 \times 10^{13}\ cm^{-2}\ sec^{-1}$ for one month. To eliminate the component due to the decay of Ta^{183} ($T_{1/2}$ = 5 days), which results from double capture of a neutron, the measurements were made one month after the end of the bombardment.

The results of the measurements are shown in Fig. 1. We observed most W^{182} γ transitions previously reported by other workers, who employed different procedures. We determined the energies of the W^{182} γ transitions, using the K and L conversion lines, with an accuracy of $\sim 0.05\%$. The determined average values of the γ-transition energies are listed in the first column of Table I. Our values of the γ-transition energies, 1158.0 and 1257.5 keV, are in good agreement with the results of [5].

Table I lists also the experimental values of the internal-conversion coefficients of α_c on the K shell for the W^{182} γ transitions in the high-energy region, and their theoretically calculated values for different multipolarities [6]. The coefficients α_c were calculated by comparison of the intensities of the conversion electrons and of the γ rays of the investigated transitions with the intensity of the conversion electrons and γ rays of the 1221.8-keV transition.

The 1221.8-keV transition is pure E2, since it occurs between levels 2^+ and 0^+. We have assumed for it the theoretical value $\alpha_c = 2.58 \times 10^{-3}$.

Comparison of the experimental and theoretical values of α_c yielded the multipolarity. The proposed values of the multipolarities of the γ transitions of W^{182}, which follow from our results, are listed in the last column of Table I.

Using the data by Murray et al [1] and Ryde et al [9] concerning the nature of the γ transitions at low energies, together with our experimental results, we can plot the level scheme of W^{182}, shown in Fig. 2.

DISCUSSION OF THE RESULTS

A characteristic of W^{182} is that high excited levels are obtained for energies > 1 MeV. In de-

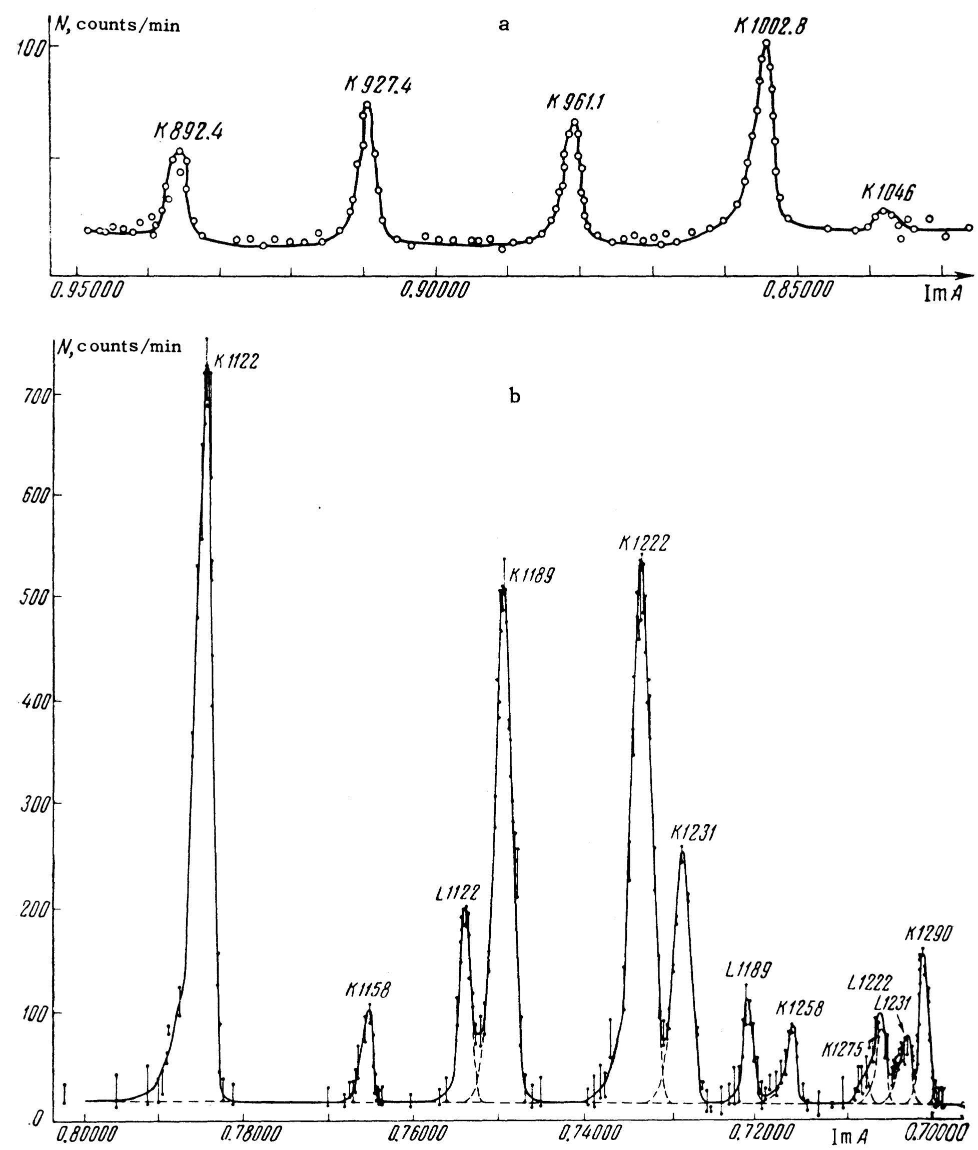

FIG. 1. Conversion spectrum of γ-transitions: a – energy range 800 –1000 keV; b – energy range 1100 –1300 keV.

formed even-even nuclei, the density of the levels increases rapidly at such energies, owing to the stronger coupling between the rotational motion and the oscillation in the vibrational and single-particle motions. Therefore in this energy region the rotational motion cannot be separated completely from the other types of motion.

However, if the intervals between the levels are not very small, then their interaction can be regarded as a perturbation[10]. We then obtain for the energy levels inside the rotational band

$$E_J = E_0 + A\,[J(J+1) - J_0(J_0+1)] - B\,[J(J+1) - J_0(J_0+1)]^2, \tag{1}$$

which coincides in structure with the formula for the pure rotational levels.

In Fig. 2 the levels are distributed by rotational bands on the basis of the energy relation (1) and the experimental values of the spins. For the sake of clarity, the different rotational bands are shifted horizontally.

In order to clarify the nature of the W^{182} levels, we have calculated the ratio of the reduced probabilities, knowing the ratio of the intensities of the conversion electrons and the multipolarities of the γ transitions. These data are compared with the theoretical relations calculated from the unified model [11] and from the theory of the non-axial nucleus [12,13] in Table II. We shall stop to discuss some of the results of the evaluation of the levels of W^{182}.

The 1221.8-keV level. The characteristics of this level, namely 2^+, are uniquely established from the nature of the 1121.6- and 1221.8-keV γ transitions (Table I). For these transitions the ratio of the reduced probabilities, in accordance with the unified model [11], is expressed in terms of the Clebsch-Gordan coefficients:

$$\frac{B(L;J_i\to J_f)}{B(L;J_i\to J_{f'})}=\left|\frac{(J_iLK_iK_f-K_i\mid J_iLJ_fK_f)}{(J_iLK_iK_f-K_i\mid J_iLJ_{f'}K_f)}\right|^2, \tag{2}$$

the calculation of which calls for knowledge only of the values of J and K and of the order of multipolarity of the γ transitions between the states under consideration. As is seen from Table II, the experimental ratio

$$B(E2;2^+,2\to 2^+,0)/B(E2;2^+,2\to 0^+,0)=1.66$$

agrees both with the calculations by the Alaga rule [11], and calculations by the theory of the non-axial nucleus [12,13]. This level, however, cannot be interpreted as a rotational level of a non-axial nucleus, for experiment deviates greatly from theory for the 892.4-keV γ transition. The best agreement is obtained with the calculations by the Alaga rule [11] under the assumption that K = 2 for this level. In this case the 1221.8-keV level should be regarded as a γ-vibrational state, due to the collective excitation. This is confirmed also by the fact that the moment of inertia, determined from the energies of the two lowest levels in each of the corresponding rotational bands, differs in the excited state (the 1221.8-keV level) from the moment of inertia of the ground state by 10%. Such a result can be obtained if the excitation is collective and not single-particle.

The 1331.6-keV level. From the nature of the low-energy γ transitions [1,9] filling this level, it follows that its characteristics are 3^+. This level is the first rotational state of the well-known rotational band with K = 2, based on the 1221.8-keV level. As can be seen from Table II, the experimental value

$$B(E2;3^+,2\to 4^+,0)/B(E2;3^+,2\to 2^+,0)=0.57$$

is in good agreement with the Alaga calculations for K = 2. The next rotational states of this band should have spins 4^+, 5^+, ... Our data are close to those of Gvozdev et al [5] and Harmatz et al. [14]

The 1258-keV level. The nature of this level still remains unclear. Thus, Gvozdev et al [5] ascribed characteristics, $J,\pi = 2^+$ and K = 0 to this level, while the characteristics $J,\pi = 1^-$ and K = 1 were assigned in earlier papers [1,15]. An interest-

Table I. Multipolarities of γ transitions of W^{182} at high energies

γ-transition energy, keV	Theoretical values of $10^3\alpha_c$[10]						Intensity of γ rays, %	Experimental values of $10^3\alpha_c$	Multipolarity of γ transition
	$E1$	$E2$	$E3$	$M1$	$M2$	$M3$			
927.4	1.8	4.6	9.5	9.6	25.5	49.0	$\leqslant 2.7$ [7.8]	7.5 ± 1.3	$M1$, $E2$ or $M1+E2$
961.1	1.7	4.3	8.5	9.0	22.8	43.0	$\leqslant 1.8$ [7.8]	9.1 ± 1.1	$E3$
1002.8	1.45	3.72	7.45	7.55	18.5	36.0	5 ± 2 [7.8]	5.8 ± 0.8	$E2$ or $E2+M1$
1121.6	1.23	3.1	6.3	6.05	14.6	27.8	100 [9[	3.16 ± 0.20	$E2$
1158.0	1,17	2.94	5.90	5.6	13.6	26	4.2 ± 0.9 [9]	4.28 ± 0.35	$E2$ or $E2+M1$
1189.2	1.11	2,80	5.70	5.3	12.6	24.5	47.5 ± 1.9 [9]	3.98 ± 0.35	$E1+M2$
1221.8	1.07	2.58	5.40	4.85	11.8	22.5	81.0 ± 4.7 [9]	2.58	$E2$
1231.6	1.04	2.52	5.2	4.6	11.4	21.8	29.1 ± 1.9 [9]	2.62 ± 0.20	$E2$
1257.5	1.00	2,38	5.1	4,45	10.8	20.5	5.1 ± 0.9 [9]	2.67 ± 0.20	$E2$
1289.5	0.96	2.30	4.9	4.20	10.0	19.0	$\leqslant 2.9$ [9]	10.4 ± 0.9	$M2$

Table II. Comparison of experimental and theoretical ratios of the reduced γ-transition probabilities from a common level

Excitation energy of common level, kV; spin and parity	Energy of γ transition, keV	Spin and parity of final state	Experimental ratios B(E2)	Theoretical ratio B(E2)			
				According to Davydov [12, 13]	by the Alaga rule		
					$K=0$	$K=1$	$K=2$
1221.8	892.4	4^+	~0.06	0,2	2.57	1.14	0.07
	1121.6	2^+	1.66	2.0	1.43	0.35	1,43
2^+	1221.8	0^+	1.0	1,0	1.0	1,0	1,0
1331.6	1002.8	4^+	0.57	0.82	0	2.5	0.40
3^+	1231.3	2^+	1,0	1.0	0	1,0	1,0
1258.0	927.4	4^+	2,92	0.18	2,57	1.14	0,07
	1158.0	2^+	1.6	2.0	1.43	0.35	1,43
2^+	1257.5	0^+	1.0	1.0	1.0	1,0	1.0
1289.7*	961,1	4^+	—	—	2,57	1.14	0.07
	1189.2	2^+	2.1	—	1.43	0.35	1,43
2^-	1289.5	0^+	1.0	—	1.0	1.0	1.0

*Experimental ratio for B(M2).

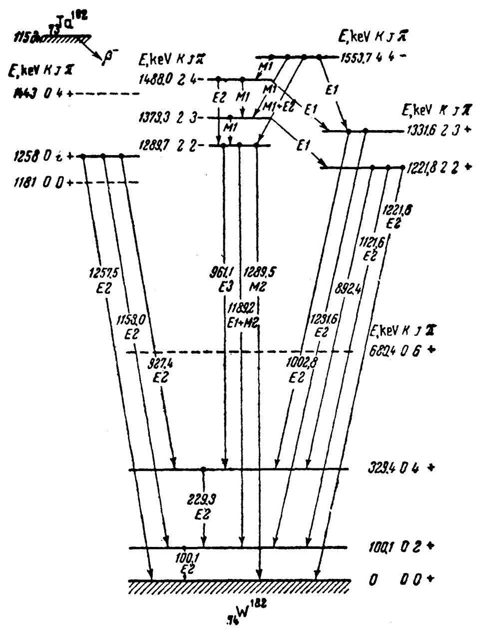

FIG. 2. Level scheme of W^{182} (the level and transition energies are in keV, K – quantum number of the rotational band).

ing result was reported recently by Kondrat'ev et al [16], who proposed that this level had a spin J = 3 with negative parity and an uncertain quantum number (K equal to zero or 2). The authors started here from the fact that the 1258-keV transition is essentially of the E3 type. Our results on the multipolarities of the 927.4-, 1158-, and 1257.5-keV γ transitions show that the characteristics of this level are 2^+. Assuming these transitions to be pure E2, we calculated the ratio of the reduced probabilities. As seen from Table II, the best agreement is obtained with calculations by the Alaga rule with K = 0, that is, this level is the first term of the β-vibrational band, the initial state of which is the level with $J, \pi = 0^+$ and K = 0. Harmatz et al [14] obtained from the Re^{182} decay ($T_{1/2}$ = 60 hr) the higher terms of this band, with K = 0. Assuming the 1443-keV level (4^+) to be the second term of this band, we calculated the empirical parameters of relation (1), and found them to be A = 12.66 and B = 0.019 keV. We then obtained an excitation energy of 1181 keV for the 0^+ level.

The 1289.7-keV level. This level is well fixed by the six transitions which begin or end with it. Starting from the multipolarities of these transitions, we see that the quantum characteristics of this level are 2^-. This level is the ground state of the known rotational band with K = 2^- and with spin sequence 2^-, 3^-, 4^-, ... The rotational band with K = 2 is established on the basis of the energy relation (1) with empirical parameters A = 14.11 keV and B = −0.029 keV, and partially also by the nature and intensities of the de-exciting emissions. As can be seen from Table II, the experimental ratio of the reduced probabilities for 1189.2- and 1289.5 keV γ transitions, assuming them to be pure M2, is found to be

$$B(M2; 2^-, 2 \rightarrow 2^+, 0)/B(M2; 2^-, 2 \rightarrow 0^+, 0) = 2.1.$$

In order to reconcile the experimental value with the theoretical value 1.43 at K = 2, we must assume that the admixture of M2 in the 1189.2-keV γ transition is smaller than 15%. However, the experimentally obtained admixture is 26%. A similar result was obtained by Vasilenko et al [17], who found the M2 admixture to be (25 ± 8)%.

The 1553.7-keV level is filled by the β decay of Ta^{182}. The characteristics assumed for it, K = 4, $J, \pi = 4^+$, agree with the established multipolarities of the γ transition in the region of lower energies [1,2,9,15]. This level can be the beginning of the fourth "rotation-vibration" band, but it can also be regarded as a "partially excited" level.

In conclusion, we take this opportunity to thank the personnel of the VVR-S reactor (water-cooled, water-moderated) of the Institute of Nuclear Physics, Uzbek Academy of Sciences, for irradiating the specimens on time.

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