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ON ALPHA DECAY OF SOME ISOMERIC STATES IN Po-Bi REGION *

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ABSTRACT

The relative and absolute α-decay probabilities of the ^{211m}Po, ^{212m}Bi and ^{212m}Po isomers are calculated and various possibilities of their spin, parity and configuration assignation are discussed.

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1. The study of the alpha decay of isomers represents a useful and often a unique way to obtain information about the structure of high spin isomers. Many authors 1)-4) have tried to describe the alpha decay of ^{211m}Po, ^{212m}Po and ^{210m}Bi on ground and excited states of daughter nuclei. In Refs.1-3 the R-matrix theory of alpha decay was used to calculate the relative probabilities which were compared with the experiment. Such a comparison for absolute values of α-decay probabilities 1)-3) meet difficulties, the theoretical values depending strongly on the channel radius R_0. In certain cases, e.g. for ^{212m}Po, even the relative probabilities depend 3) on R_0. In this paper we use the non-R-matrix shell model approach to α-decay theory 5) for the study of ^{211m}Po isomers with excitation energy $E^* = 1.45$ MeV and of new isomers 6),7) of ^{212}Bi and ^{212}Po. Here, we apply the procedure used earlier 4) in studying the isomers of ^{212}Po (with $E^* = 2.93$ MeV) and ^{210m}Bi ($E^* = 0.625$ MeV). Thus, as the theory 5) does not have free parameters, we can use not only the relative values, but also the absolute probabilities for choosing between different possible configurations, spins and parities of isomeric states. The absolute theoretical values are compared with the experiment in terms of the enhancement coefficient K, defined in Refs.4 and 5 as $K = \frac{\Gamma_\alpha^{exp}}{\Gamma_\alpha^{i.p.}} = \frac{T_{1/2}^{i.p.}}{T_{1/2}^{exp}}$, where $\Gamma_\alpha^{i.p.}$ is the alpha decay width in the independent particle (i.p.) shell model with Woods-Saxon (W-S) potential (for more details see Refs.4, 5 and 8). According to the criterion of classification of absolute values 4),5), the decays involved in this work belong to the unfavoured alpha decays (with $K \lesssim 10^2$) as coming from high spin states of nuclei and carrying large angular momenta, or to the semifavoured decays (with $\log K \approx 3$).

2. The alpha decay scheme of ^{211m}Pi is shown 9) in Fig.1. The spin, parity ($I_i^{\pi_i}$) and the wave function of the isomeric state ($E^* = 1.45$ MeV) are unknown. The only limitation 10) of the I_i value, $I \geqslant \frac{19}{2}$ comes from Wigner's estimation. The excited $\frac{5}{3}^-$, $\frac{3}{2}^-$ and $\frac{13}{2}^+$ states can, with enough precision, 11) be considered as one-hole states in 2f, 3p and 1i neutron shells. The relative values Γ_B/Γ_A, Γ_C/Γ_A and Γ_D/Γ_A were calculated by Zeh and Mang 1) in the R-matrix theory of α decay and using the harmonic oscillator (H.O.) shell model. Two facts allow the comparison with Zeh and Mang's results. First, the relative values of ^{211m}Po do not depend on the channel radius R_0, Ref.1, and second, we found that the exchange of basis from H.O. to W-S does not in this case affect the relative values, in spite of changing 5) the absolute ones.

The results of our calculations are presented in Table I in comparison with Ref.1 and also with the experiment 9). We presume, as in Ref.1, that we have for the isomeric state, configurations with two unpaired protons such as $[(1h_{9/2})^2_8\ 2g_{9/2}]_{I_i^+}$ or $[(1h_{9/2}\ 1i_{13/2})_{J_{P_i}}\ 2g_{9/2}]_{I_i^-}$. As can be seen, our results are near to Zeh and Mang's except for $I_i^{\pi_i} = \frac{29^-}{2}$ configuration. In both cases (ours and Ref.1) the relative values are not reproduced when one uses simple configurations. The most noticeable difference between theory and experiment for the D/A ratio is always underestimated. This is merely the consequence of the shell model structure and does not depend on α-decay theory. Namely, in the expression of $\Gamma_\alpha^{i.p.}$, Ref.5, the summation over the intermediate angular momenta at the given L takes place destructively for the D transition. An improvement of the D/A ratio from the admixture of other states in the $1i\frac{13}{2}$ wave function is limited by the small value of mixing coefficients 11). Another possibility is to take as additional terms in the isomeric states configurations which contribute only for the D transition 1), like

$$\Big[(1h_{9/2})^2_{J_{P_i}}\ [(2g_{9/2})^2_{J'_N}\ (1i_{13/2})^{-1}]_{J_{N_i}}\Big]_{I_i^+} \quad \text{or} \quad \Big[[(1h_{9/2}\ 1i_{13/2})^2_{J_{P_i}}\ [(2g_{9/2})^2_{J'_N}\ (1i_{13/2})^{-1}]_{J_{N_i}}\Big]_{I_i^-}$$

and choosing the angular momenta J_{P_i}, J'_N and J_{N_i} to give a maximum for the D value.

To impose the ratio B/A it is necessary to have additional terms with a constructive interference for the transition A and with a destructive one for the transition B. Unfortunately, we were not able to find such a configuration mixing by using only two components. An adding term like $[(1h_{9/2})^2_8\ 1i_{11/2}]_{I_i^+}$ which fulfills the requested properties, has a small α-width and thus its contribution is not essential. (We remark that in Ref.1 the ratio B/A was not discussed, as it was not yet experimentally determined.)

Three configurations from Table I are closer to the experiment for the relative values: $I_i^{\pi_i} = \frac{25^+}{2}, \frac{21^+}{2}$ and $\frac{23^-}{2}$. As only the relative values cannot permit to select between the proposed configurations, we must apply to the criterion of the absolute probabilities. We expect for the accounted unfavoured transition values of $\log K \lesssim 2$, in analogy with the ^{212m}Po isomer, Ref.5. The results of the calculations for K are shown in the last column of Table I. The configurations with $I_i^{\pi_i} = \frac{27^+}{2}, \frac{29^-}{2}$, having the coefficient K too large cannot be accepted, while the rejection of configurations with $I_i^{\pi_i} = \frac{19^+}{2}, \frac{21^-}{2}$ and $\frac{19^-}{2}$ is due to their small values for K. Following the same criterion, the configuration with $I_i^{\pi_i} = \frac{25^+}{2}$ is improbable and those with $I_i^{\pi_i} = \frac{23^+}{2}$ and $\frac{25^-}{2}$ are less probable.

By cumulating both criteria, two candidates still remain, namely $\Big[(1h_{9/2})^2_8\ 2g_{9/2}\Big]_{\frac{21^+}{2}}$ and $\Big[(1h_{9/2}\ 1i_{13/2})_9\ 2g_{9/2}\Big]_{\frac{23^+}{2}}$. In the frame of the i.p. shell model we cannot distinguish between the last two configurations, nor to improve the relative α values. A more complicated mixing can reach this goal, but the most probable configurations discussed here must remain the main term of the isomeric state wave function. Otherwise, the strong admixture of other configurations (such as that proposed here for the D transition) will drastically change the values of K.

3. Two new isomeric states were reported 6) in ^{212}Bi which are genetical parents, Fig.2, of isomers 6),7) in ^{212}Po. The isomers connected by β decay must have close spins. Thus, the assignation 6) of $I^\pi = 15^-$ for the 9m isomer in ^{212}Bi agrees with $I = 16^+$ of the 45s isomer of ^{212}Po. These assignations are sustained by α-decay calculations 4) which are in good agreement with experiment for the configuration $\Big[(1g_{9/2})^2_8\ (2g_{9/2})^2_8\Big]_{16^+}$. The calculations of the α-decay lifetimes of the 25m isomer of ^{212}Bi (unfavoured transition) and for the corresponding new isomer of ^{212}Po (semifavoured transition) are shown in Table I. The spin $I = 10$ for the last isomer can be excluded by using the K criterion (K value too large). This is the same for configurations like $\Big[(1h_{9/2})^2_{J_{P_i}}\ (2g_{9/2})_{J_{N_i}}\Big]_{10^+}$ with different J_{P_i} and J_{N_i} and this conclusion agrees with Ref. 7. In contradiction with Ref.7 our calculations do not support configurations, such as $\Big[(1h_{9/2})^2_8\ (2g_{9/2})_0\Big]_{8^+}$ or $\Big[(1h_{9/2})^2_0\ (2g_{9/2})_8\Big]_{8^+}$ neither their coherent mixing, as having the same value of K. The remaining possibility for $I = 8^+$ structure of ^{212m}Po, namely $\Big[(1h_{9/2})^2_0\ (2g_{9/2}\ 1i_{11/2})_8\Big]_{8^+}$ is not excluded but less probable as having the K value too large. For its parent isomer of 25m in ^{212m}Bi, the value of log K calculated with 6) $I^\pi = 9^-$ is larger than 3, which is in disagreement with the results from Ref.4 for the analogue ^{210}Bi isomer and does not reproduce the relative values. An improvement of the K value implies the decrease of the spin to $I = 7^-$ for the 25m isomer, which makes possible the assignation of less values for the spin of the corresponding ^{212}Po isomer also (e.g. $I^\pi = 6^+$). The values $I \leq 4$ can be excluded as giving too small values for K.

A more precise estimation of spins can be obtained by looking for the α decay of the new isomer of ^{212}Po on first 3^- and 5^- states of ^{208}Pb, with $E_\alpha \approx 7.88$ and 7 MeV, respectively. The loss in energy in comparison with the decay to ground state of ^{208}Pb will be partially compensated by the decrease of $L = \Delta I$, especially for the 5^- state, where $L_\alpha = 1$ if the isomer has the spin 6^+. This effect was observed earlier 4) in the case of the ^{212m}Po ($E^* = 2.9$ MeV) isomer. More detailed calculations are in process.

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Table I

^{211m}Po CONFIGURATION protons neutrons	B/A		C/A		D/A		K
	Ref.1	this work	Ref.1	this work	Ref.1	this work	
$[(1h_{9/2})^2_8\ 2g_{9/2}]_{25/2^+}$	0.09	0.205	0.17	0.207	0.31	0.512	651
$[(1h_{9/2})^2_8\ 2g_{9/2}]_{23/2^+}$	0.84	0.774	0.002	0.002	2×10^{-4}	6×10^{-4}	235
$[(1h_{9/2})^2_8\ 2g_{9/2}]_{21/2^+}$	0.11	0.137	0.05	0.142	0.01	0.108	32
$[(1h_{9/2})^2_8\ 2g_{9/2}]_{19/2^+}$		0.49		0.0026		5×10^{-4}	4.98
$[(1h_{9/2})^2_8\ 1i_{11/2}]_{27/2^+}$	0.55	1.255	0.002	0.0018	0.001	0.0031	2380
$[(1h_{9/2}\ 1i_{13/2})_{11}\ 2g_{9/2}]_{29/2^-}$	0.13	1.318	0.12	0.0017	1.3	0.0033	4440
$[(1h_{9/2}\ 1i_{13/2})_9\ 2g_{9/2}]_{25/2^-}$		0.913		0.02		0.0011	249
$[(1h_{9/2}\ 1i_{13/2})_9\ 2g_{9/2}]_{23/2^-}$		0.1624		0.17		0.234	36
$[(1h_{9/2}\ 1i_{13/2})_9\ 2g_{9/2}]_{21/2^-}$		0.549		0.0024		5×10^{-4}	4.3
$[(1h_{9/2}\ 1i_{13/2})_9\ 2g_{9/2}]_{19/2^-}$		0.107		0.115		0.0266	1.57
EXP 9)	0.036		0.238		12.8		

The relative values of α-decay probabilities and the values of $K = \frac{\Gamma^{\alpha}_{exp}}{\Gamma^{i.p.}_{\alpha}}$ calculated for the ^{211m}Po isomer.

Table II

I^π	CONFIGURATION (protons) (neutrons)	$\log_{10} K$
	^{212m}Po → ^{208}Pb(g.s.)	
10^+	$(1h_{9/2})^2_0\ (2g_{9/2}\ 1i_{11/2})_{10}$	4.81
8^+	$(1h_{9/2})^2_8\ (2g_{9/2})^2_0$	5.17
	$(1h_{9/2})^2_0\ (2g_{9/2})^2_8$	5.17
	$(1h_{9/2})^2_0\ (2g_{9/2}\ 1i_{11/2})_8$	3.94
6^+	$(1h_{9/2})^2_0\ (2g_{9/2})^2_6$	3.91
	$(1h_{9/2})^2_0\ (2g_{9/2}\ 1i_{11/2})_6$	3.22
4^+	$(1h_{9/2})^2_0\ (2g_{9/2})^2_4$	2.93
	$(1h_{9/2})^2_0\ (2g_{9/2}\ 1i_{11/2})_4$	3.77
2^+	$(1h_{9/2})^2_0\ (2g_{9/2})^2_2$	2.16
	$(1h_{9/2})^2_0\ (2g_{9/2}\ 1i_{11/2})_2$	2.53
	^{212m}Bi → ^{208}Tl(5$^+$)	
9^-	$(1h_{9/2})^1_{9/2}\ (2g_{9/2})^3_{9/2}$	3.84
	^{212m}Bi → ^{208}Tl(4$^+$)	
9^-	$(1h_{9/2})^1_{9/2}\ (2g_{9/2})^3_{9/2}$	3.04

The coefficients $K = \frac{\Gamma^{exp}_{\alpha}}{\Gamma^{i.p.}_{\alpha}}$ for the new ^{212m}Po isomer 6),7) and the ^{212m}Bi first isomer 6).

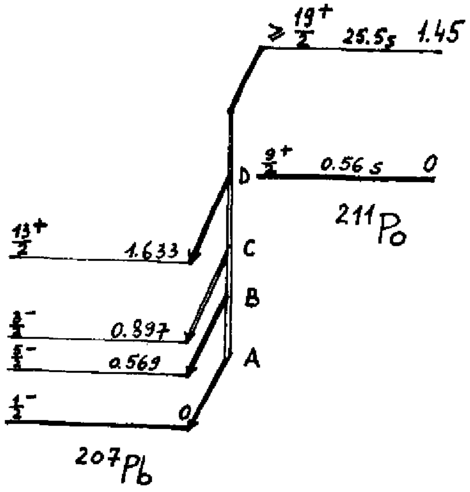

Fig.1 The decay scheme of the ^{211m}Po isomer 9).

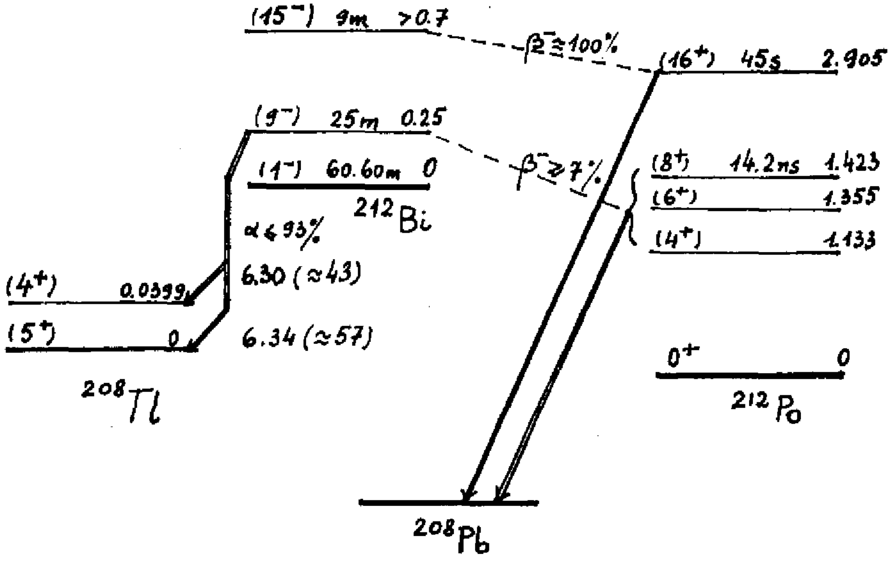

Fig.2 The decay scheme of the ^{212m}Bi and ^{212m}Po isomers 6),7).

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