ALPHA DECAY PECULIARITIES IN THE NEAR-LEAD REGION

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Alpha-particle decay of near-lead isotopes were analysed in terms of the Geiger–Nuttal formula, as well as using reduced width formalism. On this grounds a correlation between deviations from alpha decay systematics, and shape staggering effects were suggested: the sudden changes of γ^2 values for Hg, Pt and Au, for neutron number intervals 105–107, 108–110 and 102–104, respectively, are in coincidence with deformation changes confirmed by other experiments.

Investigations of nuclear properties in the near-sub-lead region have gained interest recently on account of the anomalous shape effects established in these nuclei. As reported recently [1], the isotropic shifts in mercury isotopes reveal a sudden increase in the rms radius when passing from ^{187}Hg to ^{185}Hg. Further investigations involving gamma spectroscopic methods [2–4] as well as theoretical calculations [5–6] have led to the discovery of a shape coexistence phenomenon.

It is well known that alpha decay is shape dependent. The decay constant depends on the nuclear radius via the intrinsic nuclear structure and via the barrier penetrability. It could be expected theorefore that alpha decay systematics should reflect the sudden nuclear shape changes and eventually be used as a test in nuclear deformation investigations. The present paper is a report on some of our efforts made to that effect.

The experimental data concerning the even Pt, Hg, Pb, Po, Rn and Ra nuclei were analysed and the coefficients in the Geiger–Nuttal (GN) formula were fitted for the particular elements. For trans-lead elements this was an extension of the known systematics consisting in including the newly discovered isotopes and improving somewhat the preciseness of the data.

The slight deviations of even isotopes from the determined empirical relation become more distinct if we use for their quantitative presentation the formula:

$$\log D = \log T_{1/2}^{\exp} - (A \cdot Q^{-1/2} + B),$$

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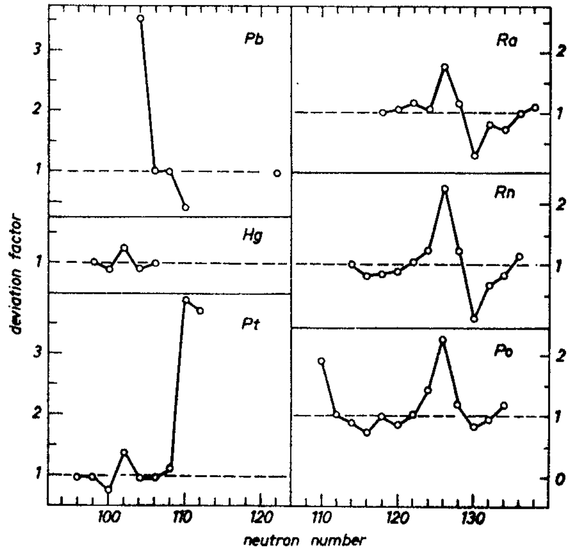
$D = T^{exp}_{1/2}/T^{syst}_{1/2}$, where $T^{exp}_{1/2}$ is the experimental value of the lifetime and $T^{syst}_{1/2}$ is lifetime defined by the systematics. The results of calculation of such "deviation factor" are presented in Fig. 1. For $N = 126$ the D value reaches its maximum for all three elements what could be expected. The acceleration of alpha-decay of the Ra, Rn and Po isotopes with 130 neutrons seems to be more difficult to explain in terms of shell model. The deviations of even Pb, Hg and Pt isotopes from the defined systematics should be inter-



Fif. 1. Deviation factor for even-even nuclei, as a function of neutron number

preted more cautiously, since the experimental data branching ratios are known in some cases with poor accuracy. However, we can assume as unquestionable the remarkable hindrance of alpha-decay for ^{186}Pb.

The dependence of the D value on the neutron number in the region of $N < 108$ for the Hg and Pt isotopes is similar. A small peak can be seen for $N = 102$ and the decay is slightly accelerated for $N = 100$. The alpha-decay of Pt isotopes with $N = 110$ and 112 is strongly hindered. It should be pointed out that the alpha-decay of Po with $N = 110$ (the only known isotope in the trans-lead region with $N = 110$) is also hindered.

As the next step the reduced widths were determined for alpha-decay of even-even nuclei of six investigated elements of odd Hg and Pt isotopes as well as of even and odd Au isotopes. The relation $\lambda = 1/\hbar \cdot P \cdot \gamma^2$ was used. The barrier penetrability P was calculated for the pure Coulomb barrier using the Bethe formula [7], and radius parameter $r_0 = 1.50$ fm.

The dependence of γ^2 on N was investigated for trans-lead elements by several group researchers, while the results for Pb, Hg and Pt were published only recently [8–10]. Our results for the reduced widths for even neutron nuclei differ in some details from those previously published, and our calculations for odd neutron nuclei provide a more complete set of data.

Figure 2 shows our results for the sub-lead region only. The reduced withs for even--neutron Hg and Pt isotopes reveal some similarity near the small minimum at $N = 102$, and moreover a resemblance between Pt and Po at $N = 110$ to 112 may be observed. The sudden decrease in the γ^2 values for Pt and Hg isotopes at $N = 105$, and $N = 107$, respectively, is very striking. It should be stressed, however, that for ^{187}Hg only the upper

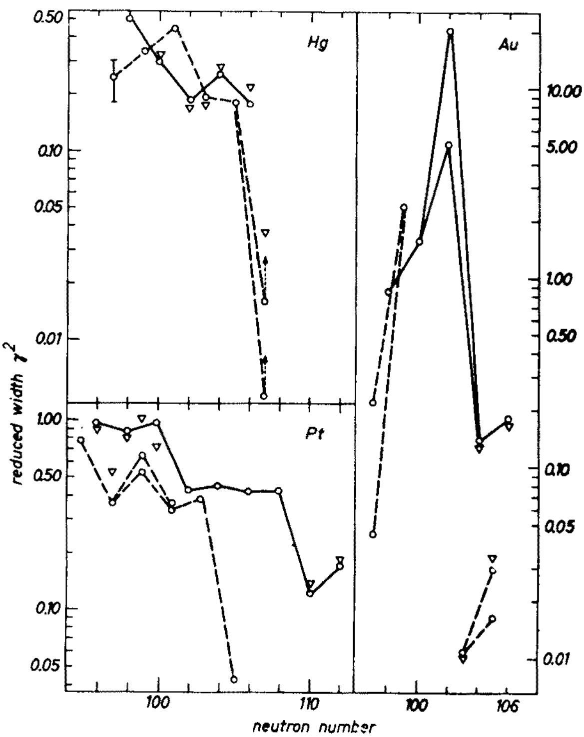


Fig. 2. Reduced widths of alpha decay for sub-lead nuclei with odd-neutron numbers (dashed line), and with even-neutron number (full line). Thr triangles indicate results of CERN group [1–5]. Typical errors — about 25%

limit of the alpha-decay branching ratio is known [8] and therefore only the lower limit of the γ^2 value can be determined. The branching ratio for ^{183}Pt was measured with better accuracy [11]. For odd neutron gold isotopes the reduced widths reaches the low value at neutron numbers $N = 103$ and 105. Even gold isotopes are characterized by an unexpectedly high value of γ^2 for $N = 102$ (for the ground and excited states) and a deep decrease at $N = 104$ to 106. It can be concluded therefore that the sudden changes of the values occur in the neutron number intervals 105–107, 103–105, 108–110, and 102-104 for Hg, Pt and Au, respectively.

The deviation of some of the even-even isotopes investigated from the determined GN systematics revealed that beside the known effect of alpha-decay hindrance for $N = 126$ there exists a remarkable hindrance for $N = 110$ and 112 (Pt, Po) smaller for $N = 102$ (Hg, Pt), and an acceleration of the alpha-decay for $N = 130$ (Po, Rn, Ra). Not one of these numbers may be associated with the filling of the neutron shell or sub-shell. Seeking shell effects in the γ^2 behaviour we can observe only the decrease of the γ^2 value to one half when going from the $2f_{7/2}$ to the $1i_{13/2}$ neutron sub-shell ($N = 100$). This effect is hardly marked in Hg isotopes.

While calculating the reduced widths for odd neutron isotopes of Hg, Pt and Au as well as for even Au isotopes, we should keep in mind that the alpha transition cannot be represented in that case by the S wave. Since our knowledge of spins and parities in this group of nuclei is only fragmentary, which makes impossible determining $\gamma_L^2(L \neq 0)$, the hindrance factor test was used. It appeared that for most of the investigated isotopes the alpha decays with considerable intensities are characterized by HF of the order of unity, what proves that the structure of the decaying isotopes in the initial and final states is similar, and that it is similar to that of the neighbouring even-even isotopes. The isotopes ^{183}Pt($HF = 13$), ^{187}Hg($HF = 19$ and 50) and ^{181}Au ($HF = 0.036$ and 0.017) are an exception. It seems that increased hindrance in the alpha-decay for ^{183}Pt and ^{187}Hg cannot be explained in terms of the shell model. From the point of view of probability of alpha-particle formation these two isotopes do not differ from the neighbouring ones. Their shell $i_{13/2}$ is only half filled. It is also difficult to explain the high HF values by assuming that alpha transitions populate with considerable intensities the excited states in the daughter nuclei. In that case the alpha-decay should have been favoured, with HF slightly higher than unity. Besides, the example of ^{185}Hg, a nucleus of structure similar to that of the considered ^{187}Hg, suggests that the favoured decay populates the ground state [12]. As far as ^{181}Au is concerned it cannot be excluded that its calculated γ^2value is the result of incorrect estimation of the alpha branching ratio (β^+ and ε decays are energetically possible [13]).

If our remarks concerning the absence of correlations between the investigated deviations from the systematics and the shell structure are right and the approximation of γ_L^2 by γ_0^2 is correct, the shape deformation with its influence on the barrier penetrability should be considered as the cause of reduced widths anomaly.

When we seek correlations between the "jumps" of the γ^2 values and the changes of deformations of nuclei characterized by shape staggering, reported recently, already the first inspection suggests that the shape effects do manifest themselves in alpha-decay. For odd mercury isotopes the sudden decrease of the γ^2 value for $N = 105$ to 107 coincides with the Otten effect [1], interpreted [5, 6] as the change of deformation from large prolate to small oblate. For even platinum isotopes we notice the decrease of reduced width for $N = 108$ to 110, i.e. those neutron numbers at which Finger et al. [14] indicates shape transition from oblate to prolate. Finally, for even neutron gold isotopes the shape staggering from prolate to oblate was demonstrated for the neutron number interval 106 to 116 [15]. Our calculated γ^2 values are getting low already for isotopes with $N = 104$. For odd platinum isotopes the data are scanty. The jump of the γ^2 value by one order of magnitude for $N = 103$ to 105 may indicate a shape change in this neutron number interval.

Although the correlation between the anomalies of the values and changes of deformations seems to be convincing, the explanation of the γ^2 jumps by shape staggering is not quite free from ambiguity.

As can be seen from the approximate Hill and Wheeler formula [16], the barrier penetrability for deformed nuclei prolate as well as oblate is greater than for spherical ones:

$$P_{\mathrm{Def}}/P_0 = \exp\{-2gm(1-X)^{1/2}(2-X)\},$$

where $m = -2/5\alpha$ for prolate nuclei ($\alpha > 0$) and $m = +1/2\alpha$ for oblate nuclei ($\alpha < 0$). The formula is written according to the Bethe [7] notation.

For odd Hg isotopes with large prolate deformation ($N = 181$, 183 and 185) the γ^2 values calculated using suitable Coulomb barrier penetrability would almost smooth out the γ^2 dependence on N and indicate that shape effects in this case do manifest themselves in alpha decay.

Another factor which could induce a change of the reduced width of alpha-decay is the difference of the initial and final shapes of nuclei. As shown by Geilikman [17], the hindrance of alpha-decay in such a case can be expressed by the formula:

$$H = \frac{2\alpha_i\alpha_f}{\alpha_i^2+\alpha_f^2}\exp\left\{-\frac{2(\beta_f-\beta_i)}{\alpha_i^2+\alpha_f^2}\right\},$$

where α is the zero point amplitude of nuclear oscillations and β is the deformation parameter of the nuclei. An eventual change of deformation of $\delta(\beta) = 0.05$ e.g. in the decay of ^{187}Hg, should cause the decrease of γ^2 by one order of magnitude. Hence, one can argue that this factor may bring its own contribution to γ^2 fluctuations in the region where nuclei are particularly liable to deformation.

It seems therefore that alpha decay systematics can be considered as a good test for nuclear anomalies. However, the simultaneous dependence of the reduced width and the barrier penetrability on nuclear radius and deformation make it impossible to extract from the observed total effect a more detailed picture of the nuclear shape.

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