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# ON THE STRUCTURE OF SPONTANEOUSLY FISSIONING ISOMERS

1. It was in 1962 that the first paper appeared [1] in which it was pointed to the existence of an isomer with a very increased probability of the spontaneous fission. Since then a large amount of experimental data on such isomers was accumulated. On the one hand, a search for new spontaneously fissioning isomers and their identification were performed, on the other hand, peculiarities of their formation were studied. For the time being the following three isomers are reliably identified $^{240m}Am$( $T_{1/2}$ = 0.0006 sec), $^{242m}Am$( $T_{1/2}$ = 0.014 sec), $^{244m}Am$( $T_{1/2}$ = = 0.001 sec) [2,3,4,5]. Recently, in irradiating $^{209}Bi$ by $^{22}Ne$ ions an isotope has been synthesized decaying by means of fission with a half-life equal to 1 min ( $T_{1/2}$ = 1 min). The behaviour of the excitation function allows us to suppose that in this case the decay of an isomer $^{228}Np$ occurs. It is interesting to note that of the four identified isomers all the four are odd-odd isotopes.

Besides the above-mentioned isotopes, in the reactions with heavy ions spontaneously fissioning isotopes with lifetimes 3,5 sec, 2,5 min and 7-10 sec [7-8] were formed. Though these isotopes have not been identified yet it may be assumed that they are spontaneously fissioning isomers, as well. Indeed, for isotopes which might be synthesized in the studied reactions the spontaneous fission period in the ground state must be much longer than the measured one.

At present there is no direct information on the excitation energy and the spin of the observable isomeric state as well as on the existence of other decay branches.

In ref. [9] an analysis of the data on the reaction $^{242}Pu$ , (d,2n) $^{242m}Am$ ( $T_{1/2}$ = 0.014 sec) was made to estimate the upper boundary of the isomer excitation energy. For $^{242}Am$ the isomer energy $\delta_i$ < 2.5 MeV. Some information on the $^{242m}Am$ isomer spin can be got by measuring the isomer ratio $a = \frac{\sigma_m(^{242}Am)}{\sigma_g(^{242}Am)}$ in various reactions ( $\sigma_m$ is the cross section for the isomer production, $\sigma_g$ is the cross section for the nucleus production in the ground state).

In ref. [10] it was established that for the reaction with thermal neutrons $^{241}Am$ (n,$\gamma$) $^{242m}Am$ $a < 10^{-6}$. While in the reaction $^{243}Am$ (n,2n)$^{242m}Am$ for neutrons of energy 14 MeV $a = 3.10^{-4}$. The spin of the isomer $^{242}Am$ appears to be larger than 8; and the fact, that the probability of formation of isomers $^{240}Am$ and $^{242}Am$ in the reactions (n,2n) is the same [3,4] indicates that their spins are likely equal.

Considering the main property of the observable isomers, namely, the increased probability for the spontaneous fission, it should be borne in mind that a factor characterising this increase $\beta = \frac{T_g}{T_m}$ ( $T_g$ is the spontaneous fission period from the ground state, $T_m$ is the isomer half-life) for identified isomers is $10^{18} \div 10^{26}$. For the sake of comparison we point out that for an isomer $^{244}Cm$ with $T_{1/2} = 0.034$ sec, $I\pi K = 6+6$ and with an energy $\mathcal{E} = 1.042$ MeV $\beta < 10^5$ /11/. This state in $^{244}Cm$ is a neutron two-quasiparticle one with configuration $622\uparrow + 624\downarrow$ /13/ x).

In a number of papers /14-15/ attempts have been made to explain the nature of the isomeric states for which the spontaneous fission probability is very strongly increased. However, these attempts fail to give a noncontradictory explanation for the spontaneously fissioning isomer structure. So, the assumption that the isomer has a four- and six- quasi-particle structure and a high excitation energy can not account, first, for comparatively large gamma decay lifetimes if transitions to rotation states are taken into account and, second, for very short spontaneous fission half-lives. It should be noticed that with respect to fission the quasi-particle excitation energy is not equivalent to the excitation energy of the compound nucleus. Assuming that a nucleus is in the excited quasi-particle state it should be borne in mind that the nucleus will pass through the same level on the fission barrier. This means that the latter may not essentially decrease /16/. Besides, high-energy quasi-particle isomeric states can appear most likely in even-even nuclei as compared to odd-odd ones.

There are some considerations that there may exist isomers with a large deformation for which either the fission barrier is presented by a two-maxima curve or the location of nuclear levels is such that it promotes fission. Attention was also drawn to the reaction mechanism being important for formation of spontaneously fissioning isomers ( see, e.g. /17/ ).

The aim of the present paper is the following: 1. study of a possible existence of isomers with deformations larger than the equilibrium deformations of nuclei in the ground states, 2. investigation of properties of such excited states ( analysis of probabilities of gamma transitions to different nuclear levels, estimation of the alpha decay lifetimes and the spontaneous fission ones), 3. determination of a possible structure of spontaneously fissioning isomers and finding of nuclei in which the isomeric states have the spontaneous fission half-lives longer (or equal) than the gamma transition ones.

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x) By $Nn_z\Lambda\uparrow$ we denote the Nilsson potential state with $K=\Lambda+\Sigma$ and by $Nn_z\Lambda\downarrow$ the state with $K=\Lambda-\Sigma$ where $N$ is the total number of oscillator quanta, $n_z$ is the number of oscillator quanta along the axis $z$, $\Lambda$ is the projection of the angular momentum on the symmetry axis, $\Sigma$ is the projection of the particle spin on this axis.

2. Let us investigate the possibility of the existence of isomeric states with deformations larger than those for nuclei in the ground states. The existence of an isomeric two-quasi-particle state with a deformation $\delta_i$ which is larger than the equilibrium deformation $\delta_o$ is possible only if the decrease of the quasi-particle state energy with increasing $\delta$ is larger than the increase (with increasing $\delta$) of the even-even core energy. Thus, we should calculate the change in the even-even nucleus energy $\mathcal{E}_o(\delta)$ depending on the deformation and the behaviour of various single- and two-quasi-particle excited states.

It is known that the calculations of the change in the total nucleus energy with increasing deformation $\delta$ with respect to the equilibrium one $\delta_o$ are not sufficiently satisfactory. So, the calculations made in ref.[18] on the basis of the superfluid nuclear model with an additional account of the Coulomb energy have led to a very low fission barrier for $^{230}U$.

Calculations based on different semiempirical formulas are not convincing too. The calculations made in ref.[19] show that the difference between the fission barriers in $^{232}Th$ and $^{254}Fm$ is from 6,1 to 3,5 MeV (according to different formulas), while the experiment gives this difference equal to 1,8 MeV. Therefore we shall not perform here subsequent calculations of changes of the total nucleus energy with increasing deformation but we shall start from the energy behaviour depending on $\delta$ which is usually taken in the liquid-drop model in considering spontaneous fission.

Let us suppose that the total even-even nucleus energy $\mathcal{E}_o(\delta)$ in the ground state has a minimum near the equilibrium deformation $\delta_o = 0{,}24$ and that this energy increases by 1÷1,5 MeV with deformation increasing to $\delta = 0{,}32 \div 0{,}35$. Fig. 1 shows the dependence of the ground state energy of $^{240}Pu$ calculated by the Nilsson scheme taking into account pairing correlations at an arbitrary cutoff of the number of average field levels concerned (further designated as case 1). A more smooth dependence which is explained by the liquid-drop model is taken as case II. The equal dependences $\mathcal{E}_o(\delta)$ were chosen for all the nuclei concerned because it is difficult to determine uniquely the change of $\mathcal{E}_o(\delta)$ in one nucleus as compared with another.

The calculations of the energies of the ground and excited single-quasi-particle states of the system consisting of an odd number of neutrons (protons) were performed by the formulae of the superfluid nuclear model[20]

$$\mathcal{E}(s_1, \delta) = E(s_1, \delta) + 2 \sum_{s \neq s_1} E(s, \delta)\, v_s^2 - \frac{C_n^2}{G_N} \qquad (1)$$

where $s_1$ is the average field level populated by a quasi-particle, $E(s,\delta)$ is the average field level energy, $C_n$ is the correlation function of the neutron system ( $C_p$ of the proton one), $2v_s^2$ is the particle density at the level $s$ , $G_N$ is the pairing interaction constant in the neutron system ( $G_Z$ in the proton one). The values of $G_N$ and $G_Z$ are the same as in ref.[21].

To determine the correlation functions $C_n$, $C_p$ and the chemical potentials $\lambda_n$, $\lambda_p$ equations were solved for each deformation $\delta$ [20]. The scheme of the Nilsson potential levels previously used in ref.[21], i.e. with parameters very close to case A in ref.[22] was employed as the average field levels. In this scheme the subshell $h_{11/2}$ in the proton system is lowered by 0,18 $\hbar\mathring{\omega}_0$ x), the subshell $i_{13/2}$ in the neutron system is lowered by 0,17 $\hbar\mathring{\omega}_0$ i.e. as in ref.[21] and a little less than in case A in ref.[22]. The energies of the Nilsson scheme levels at $\delta = 0{,}30 \div 0{,}34$ were extrapolated and at $\delta > 0{,}34$ were calculated by asymptotic formulas.

It is noteworthy that the differences of the values of $\mathcal{E}(s_1,\delta)$ for different $s_1$ but equal $\delta$ are independent of the cutoff of the number of the average field levels and of the behaviour of the even-even core energy as a function of $\delta$.

Let us consider, depending on $\delta$, the behaviour of the energies of the ground and excited two-quasi-particle states of odd-odd nuclei (one is a proton quasi-particle at the level $\nu_1$, the other is a neutron one at $s_1$ ). In the independent quasi-particle approximation, the odd-odd nucleus energy is the sum of energies (1) for the neutron and the proton systems. The behaviour of the energies of two-quasi-particle states of $^{242}$Am for case I and of the ground-state energy of $^{240}$Pu as a function of $\delta$ for cases I and II are shown in Fig. 1. It should be noted that for a given $\delta$ the energy difference $\mathcal{E}(\nu_0, s_0; \delta_1) - \mathcal{E}_0(\delta)$ between the ground state of an odd-odd nucleus (e.g. $^{242}$Am ) and an even-even one (e.g. $^{240}$Pu ) is plotted arbitrary since nothing is dependent on its absolute value. The curves for the two-quasi-particle states are obtained by adding to curves I and II the calculated values $\mathcal{E}(\nu, s; \delta) - \mathcal{E}_0(\delta)$ ( for an admitted normalization).

The $I\pi K = 1-0$ state with configuration p523↓ , n622↑ is the ground state of $^{242}$Am up to $\delta = 0{,}35$. The function $\mathcal{E}(\delta)$ for the state with $K\pi = 6+$ p523↓, n 743↑ has a minimum at $\delta = \delta_0 = 0.24$ and its behaviour resembles the behaviour of $\mathcal{E}(\delta)$ for the ground state. The function $\mathcal{E}(\delta)$ for the state with $K\pi = 9+$ p505↑, n743↑ is practically constant up to $\delta = 0{,}32$. This is due to that a fast increase

x) $\hbar\mathring{\omega}_0 = 41\,A^{-1/3}$ MeV.

of E( 505↑ ) with $\delta$ leading to a decrease of the excitation energy of this level compensates the energy increase of the even-even core.

The energy of the average field levels p505↑ and n606↑ strongly increases with increasing $\delta$ . In $^{242}$Am the approach of the levels p505↑ and n606↑ to the Fermi surface leads to that the energy of the 12- state with p505↑ and n606↑ decreases more strongly with increasing $\delta$ than the even-even core energy increases. As a result the function $\mathcal{E}$ ( p505↑, n606↑ ) has a minimum at $\delta_i$ = 0,32. Thus, an isomer with $K\pi$ = 12 - p505↑ , n606↑ has the equilibrium deformation $\delta_i$ = 0.32, i.e. it is larger than that of the nucleus in the ground state, where $\delta_o$ = 0,24. We suppose that spontaneously fissioning isomers are two-quasi-particle states in odd-odd nuclei with $\delta_i > \delta_o$ .

Fig. 1 gives the energy $\mathcal{E}(\delta)$ for a state with $K\pi$ = 6 + and p505↑ , n 761↓ which has a minimum for $\delta > \delta_o$ . However such states have a very short gamma transition lifetime due to small values of the momentum projections on the nucleus symmetry axis K and therefore we shall not be interested in.

Table 1 presents the results of calculations for cases I and II of the equilibrium deformations $\delta_i$ for isomers with $K\pi$ = 12 - and configuration p505↑ , n606↑ in the odd-odd isotopes of Es, Bk, Am, Np and Pa. The table gives the isomer energies with respect to the ground state of the nucleus for the equilibrium deformation $\delta_o$ and with respect to the lowest energy of the nucleus at $\delta = \delta_i$ . In table I there are only some nuclei in which for the 12 - state $\delta_i > \delta_o$ . So, the Es isotopes with A=252, 250, 246 and 242 have also $\delta_i$ = 0.31 ÷ 0.32 (case I) and so on. However, in a number of cases the 12-state has no minimum for $\delta_i$ > 0,30, for example, in $^{236}$Am , $^{236}$Np and in lighter isotopes. It should be noted that at $\delta$ = 0.31 ÷ 0.33 for N = 143 ÷ 151 the average field level density is large therefore the energies of the $K\pi$ =12- states slowly change from one nucleus to the other.

$K\pi$ = 11- isomers with p505↑ , n606↑ have the equilibrium deformations $\delta_i >$ 0.30. So, in $^{240}$Bk , $^{238}$Bk $\delta_i$ = 0.32 (0.33) calculated according to case I (case II). The Am isotopes with A = 238, 236, 234 and 232 have $\delta_i$ = = 0.32 (0.33), the odd-odd Np isotopes with A=226 ÷ 236 have $\delta_i$ =0.32 (0.32 ÷ ÷ 0.33), the odd-odd Pa isotopes with A = 224 -232 have $\delta_i$ = 0.31( 0.31 ÷ ÷ 0,33). The energies of these isomers in the Bk isotopes are (2.5 ÷ 3.0) MeV. in the Am isotopes (1.5 ÷ 2.5) MeV in the Np isotopes from I to 2.5 MeV and in the Pa isotopes (1.3 ÷ 2.2) MeV.

It should be noted that the values of the equilibrium deformations for the states 12- p505↑ , n606↑ and 11- p505↑ , n615↑ depend upon the behaviour of

$\mathcal{E}_0(\delta)$ and the location of the subshells $i_{13/2}$ and $h_{11/2}$. From Table I it is seen that the transition from the dependence $\mathcal{E}_0(\delta)$ given by case I to that admitted in case II has led to the increase of $\delta_i$ by 0,01 and to some decrease of the energy of the 12- and 11- states. Cases I and II are, in fact, limiting ones for the behaviour of $\mathcal{E}_0(\delta)$ and a small change in $\delta_i$ in the transition from case I to case II shows that a subsequent calculation of $\mathcal{E}_0(\delta)$ will not lead to a noticeable change of the equilibrium deformations $\delta_i$ of the isomers with $K\pi$ =12- and 11-. The calculations have resulted in a general tendency: the equilibrium deformations $\delta_i$ and the energies of these isomers increase with increasing number of neutrons and protons for nuclei in the transuranium region.

3. We assumed that spontaneously fissioning isomers are two-quasi-particle states of odd-odd-nuclei with the equilibrium deformation $\delta_i$ =0.31 ÷ 0.33 and the excitation energy with respect to the ground state of the nucleus at $\delta_o$ of the order 1÷ 1.5 MeV. We estimate roughly the probabilities of the spontaneous fission of such a type isomers in odd-odd nuclei. For this it is necessary to calculate for an isomer with $\delta = \delta_i$ the decrease of the area under the curve of the potential energy from the equilibrium deformation $\delta = \delta_o$ to the deformation $\delta_c$ corresponding to a critical shape. The estimation made on the basis of the liquid-drop model for the Am isotopes yields a critical deformation $\delta_c \approx 0.45$. It is extremely difficult to calculate the difference in the forms of the potential energy for isotopes in the isomer and ground states for $\delta > 0.40$. However, the behaviour of these energies with increasing deformations from $\delta_i$ to $\delta$ =0.40 allows us to suppose that the areas under the potential curves for the isomer and ground states are about the same in the region of $\delta$ from $\delta_i$ to $\delta_c$. Rough estimates show that for isomers with $\delta_i$ =0.32 ÷0.33 and an excitation energy about 1.5 MeV the index of the exponential determining the penetrability throughout the fission barrier will decrease by about (40 ÷ 50)% as compared with exponent for the ground state of the nucleus for $\delta = \delta_o$ . This decrease corresponds to an increase by about a factor of $10^{20}$ of the probability of spontaneous fission.

Thus, for isomers with $\delta$ =0.31 ÷ 0.33 and an energy 1÷ 1.5 MeV the probability of spontaneous fission is strongly increased as compared to that of the spontaneous fission of the nucleus in the ground state. This increase is about the same as for the Am isomers experimentally observed.

4. Let us estimate the partial lifetimes of isomers in odd-odd nuclei with $K\pi$ = 12- p505↑ , n606↑ and $K\pi$ = 11- p505↑ , n615↑ for gamma transitions to states for $\delta = \delta_o$ and to states whose equilibrium deformation $\delta \neq \delta_o$ . The overwhelming majority of states has the same equilibrium deformation $\delta_o$ as the

ground states of odd-odd nuclei. The energies of two-quasiparticle states are calculated according to (1) not taking into account the spin splitting. The rotational band are calculated for the $K \leq 10$ states, the moments of inertia are taken directly from experiment if they are the averaged values over a number of odd-odd nuclei. The E1 and E2 transitions and , as an exclusion, the M1, M2 and M3 transitions were mainly analysed. The lifetimes were estimated in the following way: the Weisskopf's value of the partial lifetime for a given transition was used and the hindrance of the $E\lambda$ transitions in deformed nuclei was taken into account using the systematics of experimental data given, e.g. in ref.[23]. In considering the K -forbidden transitions the transition probability was decreased by a factor of $10^2$ for each $\Delta K = 1$, however for $\Delta K = 5$ the transition probability was decreased by a factor of $10^9$.

A large number of gamma transitions are the F-forbidden ones[24,25]. We call the F-forbiddenness such a forbiddenness which is connected with a change in the position of the quasi-particles in the final state, as compared to the initial, one which is larger than the operator of the corresponding process allows. For example, the F-forbidden is the M3-transition from the 12-state with p505↑, n606↑ to the 9 - states with p624↑ , n734↑, since the position of both quasi-particles altered. The F-forbidden transitions are not absolutely forbidden due to that the states are not purely quasi-particle but they contain some admixtures. There is no experimental data determining the degree of the F-forbiddenness, but the absence of a number of F-forbidden beta transitions allows us to consider that $F > 10^3$. We assume that the F-forbiddenness weakens the gamma transition by a factor of $10^3$. If a transition is F-allowed then we assume a 10 times hindrance due to the difference of equilibrium deformations. In many cases the F- and K-forbiddennesses are observed simultaneously. For example, the gamma transition from the 12-12 states with p 505↑ , n606↑ to the $I\pi K = 10-8$ states with p 521 ↑ , n606↑ is K-forbidden but F-allowed in this case $\Delta K = 2$ and the gamma transition to the $I\pi K = 10-5$ state with p523↓ , n622↑ is K-forbidden with $\Delta K = 5$ ( $10^9$ times hindrance) and F-forbidden ( $10^3$ times hindrance).

We consider as an example the 12- isomer in $^{242}$Am . The scheme of the levels of $^{242}$Am for the deformations $\delta_o = 0.24$ and $\delta_i = 0.32$ is given in Fig. 2, the continuous lines denoting the energies in the equilibrium states and the dashed lines being the state energies for deformations which differ from the equilibrium ones. Here we give only a small part of the levels to which more than 99 percent of gamma rays is emitted. So, the E2 transition with an energy 300 KeV hindered $10^7$ times is performed to the 10-8 state with p633↑ , n734↑ therefore the partial lifetime for it is $10^2$ sec. The isomer has the same partial lifetime for the E1 transition with an energy 270 KeV to the 11+ 7 state with p523↓ , n734↑ hindered $10^{11}$ times. Transitions to other states give partial lifetimes which are loger than $10^{2}$ sec. In a similar way we estimated the partial lifetimes for gamma transitions of isomers for which $\delta_i > 0.30$ in all odd-odd nuclei.

The results of estimations of the partial lifetimes for gamma transitions of the $K\pi = 12-$ isomers with p505↑ , n606↑ for cases I and II are given in Table 1. As a rule lifetime is determined by transitions to many states, however, there are cases ( for which the values of $T_\gamma$ are in brackets) when $T_\gamma$ is determined by one transition, i.e. when there is a strong dependence on the calculated energy of the two-quasi-particle state. For example, in $^{242}$Bk the EI transition with an energy 250 KeV to the 11 + 10 state with p633↑ , n606↑ and an energy 1150 KeV is hindered $10^{3}$ times and for it $T_\gamma = 10^{-5}$ sec. Transitions to other states yield the lifetime $T_\gamma \approx 10^{-2}$ sec. The transition from case I to case II leads to an increase of the lifetime of isomers, on the average, by a factor of 10.

From Table 1 it is seen that some isotopes of Pa, Np, Am have long gamma transition lifetimes. The 12-isomers in the isotopes of Bk and Es have much shorter partial lifetimes for gamma transitions.

The lifetimes of the 11-isomers with p505↑ , n606↑ in the isotopes of Bk and Am are extremely short. If the subshell $i_{13/2}$ is lowered by 0.10 $\hbar\mathring{\omega}_0$ but not by 0.17 $\hbar\mathring{\omega}_0$ then in $^{226}$Np , $^{228}$Np and $^{230}$Np the 11-isomers will have the gamma transition lifetimes $T_\gamma = 10^{-2} \div 10^{-4}$ sec.

Let us estimate the alpha-decay lifetimes of the isomers. We consider the alpha decay from the 12-isomer to the same isomer in the daughter nuclei. This transition is favorable-favorable, the alpha particle energy is equal to the energy of the transition between the ground states of these nuclei plus the difference of isomer energy in the parent and the daughter nuclei. The transition to the ground state of the nucleus for $\delta = \delta_0$ is unfavorable-unfavorable and its hindrance factor is of the order $10^{5} \div 10^{6}$. We consider a case of $^{246}$Es the most favorable with respect to the alpha decay. The experimentally found energy of alpha particles is 7.4 MeV /26/ and the isomer energy is 2 MeV. The alpha particle energy in the transition to the ground state $^{242}$Bk = 9.4 MeV. If the $10^{6}$ times hindrance is taken into account then we get $T_\alpha \approx 1$ day. While in the transition to the 12-isomers of $^{242}$Bk the alpha-particle energy is about 8 MeV. since the difference of the isomer energies is 0.6 MeV. The life time is therefore 1 min., i.e. it is much longer than that for gamma transitions. In the Bk isotopes the estimations of the minimal alpha-decay lifetimes give the values of the order 5÷20 hours, in the Np isotopes they are much longer.

Thus, the partial alpha - decay lifetime of $K\pi = 12-$ isomers with p 505↑ , n 606↑ are much longer than the gamma-transition and spontaneous fission lifetimes.

5. Let us consider the possibility of the existence of spontaneously fissioning isomers in odd-A and even-even nuclei.

In odd-A nuclei $N = 145 \div 153$ in the state 606↑ the equilibrium deformation calculated for case I is $0.29 \div 0.31$ and for case II it is $0.30 \div 0.32$. However, the minimum of the function $\mathcal{E}$ (606↑ , $\delta$ ) depending on $\delta$ is expressed far more weakly than in odd-odd nuclei. The energies of the isomers 606↑ are $(0.5 \div 1.5)$ MeV, and the gamma-transition lifetimes are $10^{-5} \div 10^{-14}$ sec. So, for $^{241}Pu$ the 606↑ state has an energy 0.9 (0.8) MeV and $T_\gamma \gtrsim 10^{-6}$ sec., in $^{247}Cm$ the energy is equal to 1.4 (1.2) MeV and $T_\gamma \gtrsim 10^{-12}$ sec. Thus, in odd-A nuclei with $N = 145 \div 153$ the probability of spontaneously fission is noticeably decreased and the gamma-transition one is noticeably increased as compared with neighbouring odd-odd nuclei. In the odd-A nuclei with $N = 133 \div 143$ the 606↑ and 615↑ states have in most cases the same equilibrium deformation as the nucleus in the ground state.

In odd-Z nuclei the calculation of the equilibrium deformations for the 505↑ states in case I give $\delta_i \approx \delta_o \approx 0.24$ and in case II they lead to a weakly pronounced minimum for $\mathcal{E}$ (505↑ , $\delta$ ) being appeared in the nuclei with $Z = 95, 97, 99$ at $\delta_i = 0.30 \div 0.31$. However, the partial gamma transition lifetimes of these states are very short.

Thus, according to the calculations performed the probability of finding spontaneously fissioning isomers in odd-N and odd-Z nuclei is extremely small.

We consider the possibility of the existence of isomers with $\delta_i > \delta_o$ in even-even nuclei. The calculations show that in some isotopes of Pu, Cm and other elements there are two-quasi-particle states with $\delta_i \lessapprox 0.29 \div 0.30$ and with an energy about 3 MeV. For example. the neutron states with $K\pi = 9+$ 622↑ , 606↑ , with $K\pi = 11-$ 734↑ , 606↑ , with $K\pi = 10+$ 624↓ , 606↑ , with $K\pi = 10-$ 743↑ 606↑ and the proton states with $K\pi = 8+$ 523↓ , 505↑ , with $K\pi = 8-$ 642↑ , 505↑ . The gamma transition lifetimes of these states are shorter than $10^{-7}$ sec. Thus, the possibility of discovering spontaneously fissioning isomers in even-even nuclei is also very small.

6. The investigation performed showed that it is possible to explain the spontaneously fissioning isomers discovered in 1962. The spontaneously fissioning isomers are two-quasi-particle excited states with $K\pi = 12-$ p 505↑ , n 606↑ and with $K\pi = 11-$ p 505↑ , n 615↑ in odd-odd nuclei. The most likely region of the values of N and Z for such isomers to exist are indicated on the basis of the

calculations concerned. Undoubtedly, the calculatinns do not claim to an exact determination of the boundary of this region.

It should be noted that the calculations are rough. The behaviour of the energy $\mathcal{E}_o(\delta)$ in both cases as well as the estimates of the spontaneous fission lifetimes should be especially criticized. However, if we take into account that cases I and II are practically limiting ones for $\mathcal{E}_o(\delta)$ and that the transition from case I and II does not change the basic conclusions it is undoubtful that isomers with the equilibrium deformations larger than those of nuclei in the ground states may exist.

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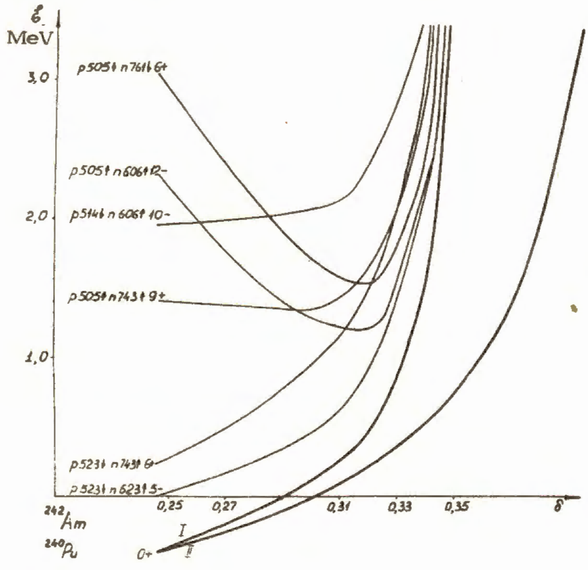


Fig.1.

Energy behaviour of two-quasi-particle states of $^{242}$Am .

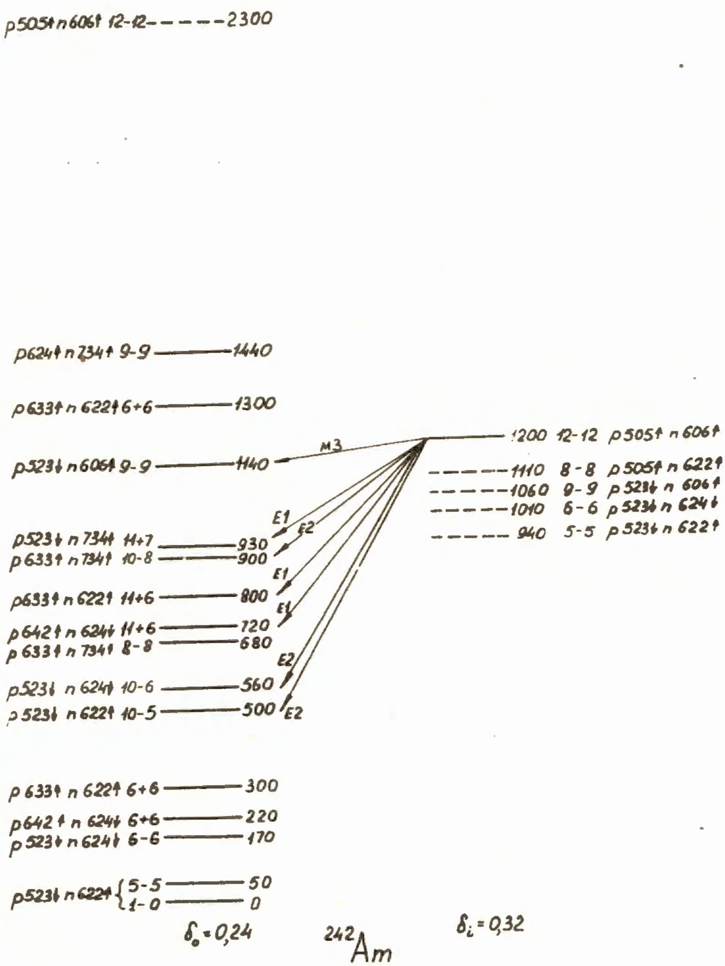
p505↑n606↑ 12-12 2300
p624↑n734↑ 9-9 1440
p633↑n622↑ 6+6 1300
p523↓n606↑ 9-9 1140
p523↓ n734↑ 11+7 930
p633↑ n734↑ 10-8 900
p633↑ n622↑ 11+6 800
p642↑ n624↓ 11+6 720
p633↑ n734↑ 8-8 680
p523↓ n624↑ 10-6 560
p523↓ n622↑ 10-5 500
p633↑ n622↑ 6+6 300
p642↑ n624↓ 6+6 220
p523↓ n624↓ 6-6 170
p523↓ n622↑ 5-5 50
1-0 0
M3
E1
E2
E1
E1
E2
E2
1200 12-12 p505↑ n606↑
1110 8-8 p505↑ n622↑
1060 9-9 p523↓ n 606↑
1010 6-6 p523↓ n 624↓
940 5-5 p523↓ n 622↑
$\delta_0 = 0{,}24$
$^{242}Am$
$\delta_i = 0{,}32$

Fig.2.

## Table I

Isomers in odd-odd nuclei with $K\pi = 12^-$ and configuration $p505\downarrow$, $n606\uparrow$.

| Nucleus | Case I | | | | Case II | | | |
|---|---|---|---|---|---|---|---|---|
| | $\delta_i$ | Isomer energ. (MeV) with respect to ground state for $\delta = \delta_0$ | $\delta = \delta_i$ | $T_\gamma$ sec | $\delta_i$ | Isomer energ. (MeV) with respect to ground state for $\delta = \delta_0$ | $\delta = \delta_i$ | $T_\gamma$ sec |
| $^{248}Es$ | 0,32 | 2,2 | 1,2 | $10^{-7}$ | 0,33 | 1,8 | 0,9 | $10^{-6}$ |
| $^{244}Es$ | 0,32 | 1,8 | 0,9 | $10^{-8}$ | 0,33 | 1,6 | 0,7 | $10^{-7}$ |
| $^{246}Bk$ | 0,32 | 1,8 | 0,8 | $10^{-3}$ $(10^{-4})$ | 0,33 | 1,5 | 0,6 | $10^{-1}(10^{-3})$ |
| $^{244}Bk$ | 0,32 | 1,6 | 0,7 | $10^{-5}$ | 0,33 | 1,3 | 0,4 | $10^{-2}(10^{-4})$ |
| $^{242}Bk$ | 0,31 | 1,4 | 0,7 | $10^{-2}(10^{-5})$ | 0,32 | 1,2 | 0,5 | $10^{-1}(10^{-4})$ |
| $^{240}Bk$ | 0,31 | 1,4 | 0,7 | $10^{-3}(10^{-7})$ | 0,31 | 1,2 | 0,6 | $10^{-2}(10^{-7})$ |
| $^{246}Am$ | 0,32 | 1,7 | 0,7 | $10^{-3}(10^{-6})$ | 0,34 | 1,5 | 0,3 | $10^{-2}(10^{-5})$ |
| $^{244}Am$ | 0,32 | 1,5 | 0,5 | 0,1 | 0,33 | 1,3 | 0,2 | 1,0 |
| $^{242}Am$ | 0,32 | 1,2 | 0,2 | $10^{2}$ | 0,32 | 1,0 | 0,3 | $10^{3}$ |
| $^{240}Am$ | 0,32 | 1,1 | 0,2 | 1,0 | 0,32 | 0,9 | 0,2 | $10^{3}$ |
| $^{238}Am$ | 0,31 | 1,0 | 0,3 | $10^{-3}$ | 0,31 | 0,9 | 0,3 | $1{,}0(10^{-2})$ |
| $^{244}Np$ | 0,32 | 1,6 | 0,6 | $10^{-7}$ | 0,33 | 1,3 | 0,3 | $10^{-2}(10^{-7}$ |
| $^{242}Np$ | 0,32 | 1,3 | 0,3 | $10^{-5}$ | 0,33 | 1,1 | 0,1 | $1{,}0(10^{-4}\ )$ |
| $^{240}Np$ | 0,31 | 1,0 | 0,3 | $10^{2}$ | 0,32 | 0,9 | 0,2 | $10^{2}$ |
| $^{238}Np$ | 0,31 | 0,9 | 0,1 | $10^{4}$ | 0,31 | 0,7 | 0,1 | $10^{6}$ |
| $^{236}Pa$ | 0,30 | 0,7 | 0,1 | 1,0 | 0,30 | 0,5 | 0,1 | $10^{2}$ |