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Облегченные и необлегченные α-переходы в сверхтяжелых элементах с $Z \simeq 114$

α-переходы в сверхтяжелых элементах с $Z=112$, 114, 116 рассмотрены в рамках оболочечного приближения не R-матричной теории α-распада.

Показано, что в ряде случаев последовательный учет эффектов ядерной структуры может приводить к увеличению времени жизни сверхтяжелых ядер по сравнению со значениями, полученными на основе эмпирических интерполяционных формул.

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Favoured and Unfavoured α-Transitions of Superheavy Elements around $Z = 114$

The α-transitions of superheavy elements with $Z=112$, 114, 116 are studied in the framework of shell model approach to non-R-matrix theory of α-decay.

Some cases are put on evidence for which the account for nuclear structure leads to greater life times than the empirical ones.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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1. Theoretical studies[1-3] lead to the conclusion that superheavy nuclei with Z around 114 must be relatively stable against beta-decay and that their fission life times must be by some orders of magnitude greater than alpha life times. Thus, predictions concerning alpha decay are of first importance in understanding the stability of nuclei in this region.

Calculations of alpha decay energies were made on the basis of mass formulae taking into account shell corrections also[3]. But alpha life times were estimated mainly on the basis of empirical formulae of the Geiger-Nuttal type[3,9], that is accounting for their string energy dependence, but without an effective account of the influence of nuclear structure.

Some attempts to predict alpha life times of superheavy nuclei by shell model calculations were performed also[4,5]. These calculations are based on the R-matrix theory of alpha decay. But it is known[6] that R-matrix theory does not yield correct absolute values for the alpha widths. Furthermore, alpha widths calculated in this way depend either on the channel radius parameter[4], or on the optical model parameters[5]. Therefore these results cannot be very concludent.

Recently, a consistent analysis of the influence of nuclear structure on the alpha decay of spherical nuclei was performed[7,8] on the basis of an integral formula for alpha widths[10], which does not contain any free parameters. In the present paper, the results of this analysis are extrapolated to the region of superheavy nuclei. After a short review of the results obtained by the integral formula, the favoured and unfavoured alpha transitions of superheavy nuclei are considered.

2. The integral formula for alpha decay widths has the form [10]

$$\Gamma^{\alpha}_{if} = 2\pi \sum_{L} |\langle A\{F_L u^{I_i M_i}_{L\sigma_f I_f}\} | V_{\alpha\, A-4} | \Phi^{I_i M_i}_{\sigma_i} \rangle|^2 , \qquad (1)$$

where the function F_L is a regular Coulomb function normalized to a δ-function in energy,

$$u^{I_i M_i}_{L\sigma_f I_f} = \sum_{M_f} C^{I_f L I_i}_{M_f M M_i} Y_{LM}(\Omega_{\vec{R}}) \Psi_{\alpha} \psi^{I_f M_f}_{\sigma_f} \qquad (2)$$

is the channel wave function, and

$$V_{\alpha\, A-4} = \sum_{L=1}^{4} \sum_{j=5}^{A} V_{ij} \qquad (3)$$

is the nuclear part of the alpha particle - final nucleus interaction.

Calculations were performed with this formula using shell model wave functions for the initial and final nuclei and approximating the interaction (3) according to the basic assumptions of the same model [7,8].

The selfconsistent field was taken of Woods-Saxon type and the corresponding one-nucleon functions were used. This is an important point since the earlier used [4,5] harmonical oscillator potential with infinite depth cannot yield the correct description of the behaviour of wave functions at the nuclear surface, especially for superheavy nuclei. The computational problems which appeared in this connection were solved [11] due to a method of separating the centre-of-mass motion of clusters in nuclei [12].

The results of the calculations performed for a large number of spherical alpha emitters [7,8] demonstrated that a theoretical analysis of the alpha decay can be done even on the basis of the most simple independent particle shell model. This analysis was performed [7] in terms of the ratio

$$K_{exp} = \frac{\Gamma^{exp}_{\alpha}}{\Gamma^{i.p.}_{\alpha}} = \frac{T^{i.p.}_{1/2}}{T^{exp.}_{1/2}} , \qquad (4)$$

where the index "exp". indicates the experimental values, while "i.p.", the values calculated with independent particle shell model.

The theoretical width $\Gamma^{i.p.}_{\alpha}$ includes the energy dependence of alpha widths through the Coulomb function F_L (see formula (1)) and thus the ratio K_{exp} is energy-independent. So, these ratios can be considered as a sort of spectroscopical factors measuring the influence of nucleon-nucleon correlations on alpha decay probabilities.

The results of the independent particle shell model calculations (see fig. 5 from ref. [7]) put in evidence that a classification of alpha transitions can be done in terms of the ratios K_{exp}. The values K_{exp} for favoured transitions are the greatest ones and are situated in a narrow band. For unfavoured transitions, the ratios K_{exp} take on the smallest values. One can distinguish a third class of transitions also, with values K_{exp} of about 10 times smaller than for neighbouring favoured transitions. This is the case of the odd Bi isotopes ($Z = 83$, even N) and of the nuclei with even Z and $N = 125$, 127. These transitions are named "semi-favoured".

The assumption that this classification is due to the differences in the influence of nucleon-nucleon correlations on different types of transitions [7] was confirmed by the alpha width calculations which took into account residual interactions [8].

3. In order to use the above described formalism to the study of superheavy nuclei, let us define, in analogy with the ratios K_{exp}, the ratios

$$K = \frac{\Gamma_\alpha^{\text{empiric}}}{\Gamma_\alpha^{\text{i.p.}}} = \frac{T_{1/2}^{\text{i.p.}}}{T_{1/2}^{\text{empiric}}}, \qquad (5)$$

where $\Gamma_\alpha^{\text{empiric}}$ are the alpha widths obtained in ref./3/ by the empirical formulas of Viola and Seaborg /13/.

For the calculation of the theoretical alpha widths $\Gamma_\alpha^{\text{i.p.}}$, the parameters of the Woods-Saxon shell model selfconsistent potential are obtained as a spherical limit of the folded Yukawa potential /3/. They have the following values for the nucleus with Z = 114 and A = 298:

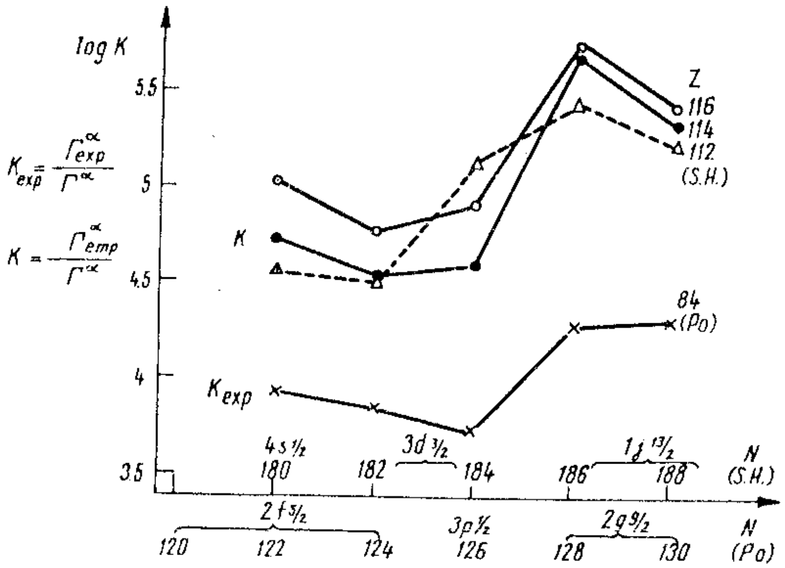
$$1/a = 1.517\ \text{fm}^{-1} \qquad V_p = -60.64\ \text{MeV}$$

$$r_0 = 1.262\ \text{fm} \qquad V_N = -44.36\ \text{MeV} \qquad \kappa = 0.353$$

4. Calculations of ratios K, where performed firstly for favoured alpha transitions in the superheavy region /14/ and namely for the $0^+ \to 0^+$ transitions of even isotopes with Z = 112, 114 and 116. In the figure the values logK for these nuclei are compared with the values $\log K_{exp}$ for favoured transitions of even Po isotopes, using two scales for the neutron number N.

Firstly, it can be observed that the behaviour of the ratios K and K_{exp} is very similar. For instance, the same jump is appearing in the values logK and $\log K_{exp}$ at the magic neutron numbers. This hints to a similarity in structure for these chains of isotopes.

Secondly, let us compare the values $\log K_{exp}$ (see fig. 5 from ref./7/) for the rare-earth region (of about 3.5), the values $\log K_{exp}$ for the lead region (of about 4.5) and the values logK for the present superheavy nuclei (of about 5.5). An increase of the ratios K with increasing A can be observed. This situation suggests that the importance of the influence of nucleon-nucleon correlations on alpha decay widths is increased for nuclei with large mass-numbers A.



The comparison between the values of ratios K_{exp} for the chain of Po isotopes and the values of ratios K for superheavy elements with Z = 112, 114 and 116. The values of logK and $\log K_{exp}$ are plotted against the number of neutrons, using two scales.

5. Let us consider now the alpha decay of superheavy nuclei with N = 185 and even Z. Since the initial and final nuclei have in this case respectively one particle over and one hole under the closed shell it can be assumed that their spins are correctly predicted by the independent particle shell model. Furthermore, the transitions are of the ground state to ground state type and the alpha decay energies are evaluated for them in ref./3/. Thus, having all the necessary data, calculations were performed for the widths $\Gamma_\alpha^{\text{i.p.}}$ and the ratios K. The results are given in the table.

Table

The value K for superheavy nuclei with N = 185

Nucleus				
	Z	112	114	116
	A	297	299	301
logK		5.52	5.50	5.31

It can be seen that the ratios K are of the same magnitude as for the neighbouring favoured transitions (see also the figure).

But, the analogy in structure of the present ($N = 185$) nuclei with nuclei of $N = 125, 127$ and with even Po isotopes suggests that these transitions are semifavoured. From the above presented classification/7/ of alpha transitions it results that for semifavoured transitions the ratios K must be smaller than for the favoured ones.

Thus, as it can be seen from the table, the values of ratios K are greater than expected. This means that the empirical half-lives $T_{1/2}^{empiric}$ for semifavoured transitions are under-estimated, as a consequence of neglecting the structure effects in determining the hindrance factors/13/.

The amount of this underestimation must be at least a factor of 10, as it was the case for lead region (see fig. 5 from ref./7/). It was demonstrated/7/ that the splitting between the values of ratios K for favoured and for unfavoured transitions is due to the influence of nucleon-nucleon correlations on α-decay widths. For the superheavy nuclei this influence was shown above to be increased. Consequently, the empirical half lives $T_{1/2}^{empiric}$ for the transitions are underestimated by a factor which can vary from 10 up to 100.

7. For the case of unfavoured transitions in the superheavy region, the calculations of ratios K are difficult, because of lack of information both about spins of initial and final nuclei and about the alpha-decay energies. But the average hindrance factors given by Viola and Seaborg/13/ for unfavoured α-transitions are of the same magnitude as for semifavoured ones. In fig. 5 from ref./7/ it can be seen that the ratios K_{exp} are of about two orders of magnitude smaller for unfavoured transitions than for semifavoured ones. Thus, it can be expected that in this case the empirical half-lives will be underestimated by at least three orders of magnitude.

Consequently, it can be supposed that the most drastically hindered alpha decays because of the structure effects can be those of superheavy nuclei analogous to ^{210}Bi, ^{210m}Bi, ^{211m}Po and ^{212m}Po nuclei (see refs./7,8/). In the last three cases we have to do with high spin isomeric states which have much greater life times than the corresponding ground states. This is due to the fact that the forbiddenness of alpha decay with large angular momenta partially compensates the effect of increased alpha decay energy. In the superheavy region, at the passing from the closed shells $4s_{1/2}$ and $3d_{3/2}$ to $1j_{13/2}$ or $1k_{17/2}$ levels, the appearance of high spin superheavy isomers with increased alpha stability is possible. The population of such states can act as an "isometric trap" in which the superheavy nucleus may remain sufficiently long time to be identified.

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REFERENCES

1. Bohr A., Mottelson B.R. Phys.Scr., 1974, 10A, p. 13.
   Bolsterli M. et.al. Phys.Rev., 1972, C5, p. 1050.
2. Beiner M. et al. Phys.Scr., 1974, 10A, p. 84.
3. Fiset F.O., Nix I.R. Nucl.Phys., 1972, A193, p. 647.
4. Carjan N. et al. Rev.Roum.Phys., 1971, 16, p. 811.
5. Dumitresku O. et al. Rev.Roum.Phys., 1976, 21, p. 829.
6. Mang H.J. Ann.Rev.Nucl.Sci., 1964, 14, p. 1.
7. Furman W.I. et al. JINR, E4-11286, Dubna, 1978.
8. Furman W.I., Holan S., Stratan Gh. JINR, E4-11287, Dubna, 1978.
9. Kolb D. In: Proceedings of the Summer School on Heavy Ion Physics, Predeal, 1976.
10. Furman W.I., Kadmensky S.G. JINR, P4-8729, Dubna, 1975 and Particles and Nuclei, 1975, 6, p. 469.
11. Holan S. JINR, P4-9278, Dubna, 1975.
12. Furman W.I. et al. Nucl.Phys., 1975, A239, p. 114.
13. Viola V.E., Seaborg G.T. Inorg.Nucl.Chem., 1966, 28, p. 697 and Inorg.Nucl.Chem., 1966, 28, p. 741.
14. Holan S., Stratan G. In: Proceedings of the Summer School on Heavy Ion Physics, Predeal (1976).

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