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Half-life Landscape in the Largest-mass Part of Nuclidic Chart

Obraz czasów życia w obszarze najcięższych jąder atomowych

Расположение времен жизни на карте нуклидов в области сверхтяжелых масс

Our view of the heaviest nuclei is continuously developing due to a continuing progress of both experimental and theoretical research in this field. The experimental research results in the synthesis and study of the properties of new isotopes and also of new elements (cf. the review papers [1-3]). The theoretical studies lead to a description of these properties and to predictions for them for nuclei not yet observed.

The property which decides on the possibility to synthesize a nucleus and to study it, is (besides the cross-section for the synthesis) its stability with respect to various kinds of decay. For heaviest nuclei, the most important decays are: spontaneous fission and alpha decay (beta decay becomes important only when one goes far from the beta-stability line). The stability is characterized by the half-life of a nucleus.

In the present paper, we will just concentrate on the spontaneous-fission (T_{sf}) and alpha-decay (T_{α}) half-lives. Nuclei with the atomic number $Z \geqslant 102$ are considered. Main attention is paid to nuclides in the region between that known experimentally and the region of hypothetic superheavy elements (SHE).

Systematics of alpha half-lives T_{α} is rather smooth. The contribution of the shell effects to them is rather small. This is because only the difference of these effects between rather close nuclei (differing by only two protons and two neutrons) contributes. Thus, the predictions for T_{α} of unknown nuclei is relatively simple and reliable. The contribution of the shell effects to T_{sf} is, however, much larger and the systematics of these half-lives is more complex. Still, it reveals that the semiclassical description of the half-lives basing on the macroscopic-microscopic fission barriers is rather good (cf. e.g. refs. [4,5]). Really, the experimental values of T_{sf} measured for 40 even-even nuclides are reproduced in [4] within a factor of 20, on the average. These calculations, based on the static description of the fission process, use only one adjustable parameter. The factor 20 (i.e. slightly more than one order) is really small if one takes into account the fact that the experimental T_{sf} vary inside the limits from about 10^{16} y (isotopes of uranium) down to about 1 ms (isotopes of the element 104), i.e. by about 26 orders. Dynamical description of T_{sf} for the same 40 nuclides, performed in [5], reproduces their values within a slightly larger factor of 50. It does not make, however, use of any adjustable parameter. Both calculations are done for nuclides with the neutron number $N \leqslant 164$. An extension of the study to N=170, performed in [6], showed a fast decrease of T_{sf} with increasing N, down to the values smaller than 10^{-11} s for N=170, for all elements investigated (Z=100-110). This means that the calculations predict a deep instability of nuclei situated between the region of experimentally known nuclei and the SHE region. Thus, it supports a long-lasting idea according to which the superheavy nuclei constitute an island separated from the experimental region by a region of deep instability.

Another picture is obtained, however, with the potential energy calculated recently [7]. This energy is obtained with the use of the Woods-Saxon single-particle model [8], in distinction to the potential energy of [6], which is based on the Nilsson model [9]. The energy of [7] leads to rather high fission barriers E_f. The barriers are shown in fig.1, taken from [10]. One can see that for nuclei with $N \approx 170$, the

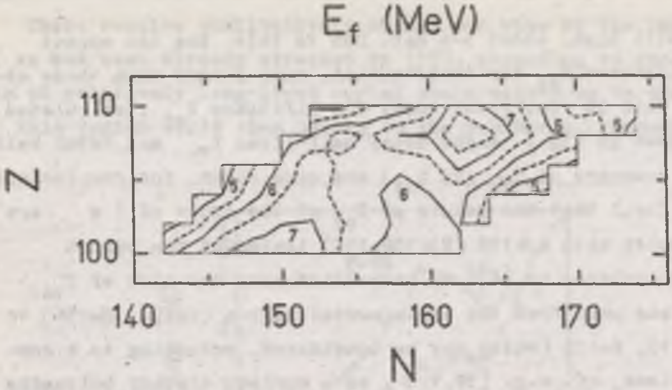

Fig.1. Contour map of the height of the fission barrier E_f calculated as a function of the proton Z and neutron N numbers for Z=100-110

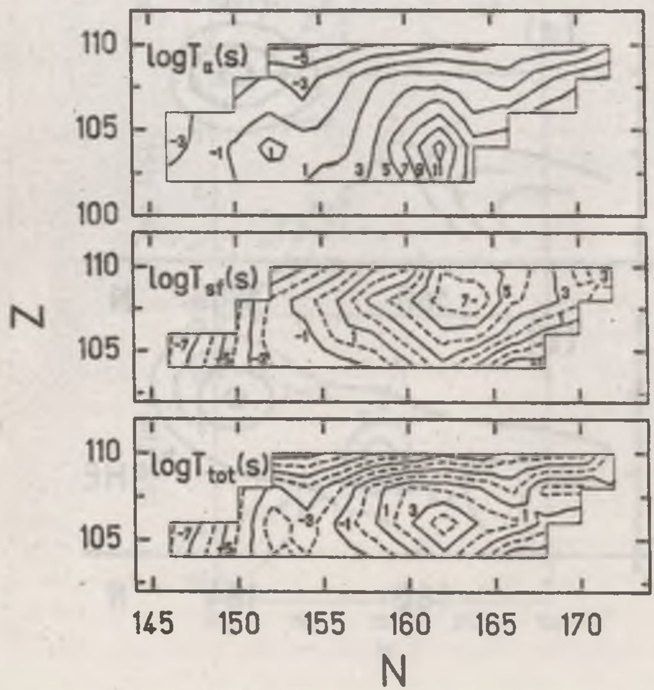

Fig.2. Contour maps of logarithm of the alpha-decay T_α , spontaneous fission T_{sf} and total T_{tot} half-lives (in seconds), calculated for Z=104-110

barriers are still high, about 5-6 MeV. Due to this, one can expect long fission lifetimes T_{sf} for these nuclei, much longer than those obtained in [6]. This is really the case. The lifetimes T_{sf} , calculated in [10], are shown in fig.2. Alpha-decay half-lives T_{α} and total half-lives T_{tot} (as composed of T_{α} and T_{sf}) are also shown, for completness. One can see in fig.2 that the values of T_{sf} of the order of 1 m are obtained for nuclei with $N \approx 170$ ($Z \approx 108$-110) instead of the values $T_{sf} < 10^{-11}$ s calculated in [6]. An inspection into the plot of T_{tot} shows that one can pass from the experimental region (Z=104, N=158) to the nucleus Z=110, N=172 (which may be considered, according to a number of calculations, cf. e.g. [11,12] , as a nucleus already belonging to long-lived superheavy region) through nuclei with a lifetime not smaller than about 0.1 s.

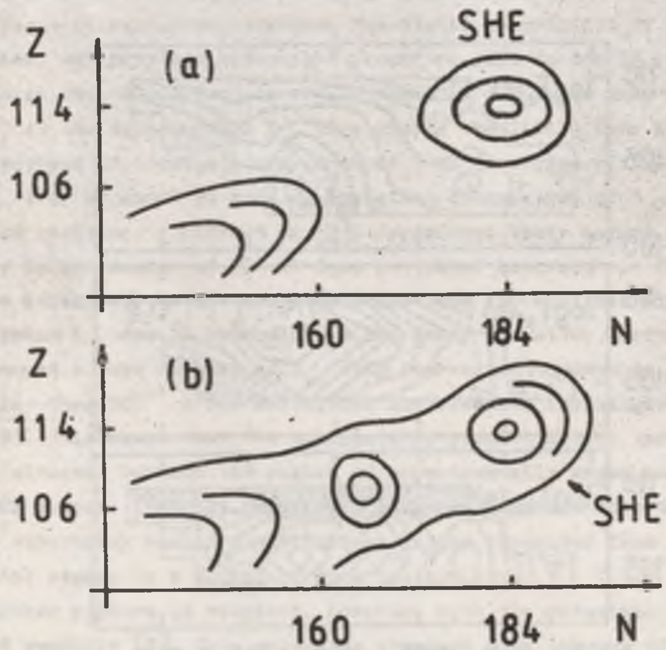

Fig.3. Qualitative illustration of the shape of regions of relatively long-lived heavy nuclei, as believed earlier (a) and expected presently (b)

These results qualitatively change our view of the heaviest nuclei, as has been already stressed in [13]. According to them, the peninsula of relatively long-lived nuclei would extend up to the SHE region. This region would then belong to the peninsula, instead of consti-

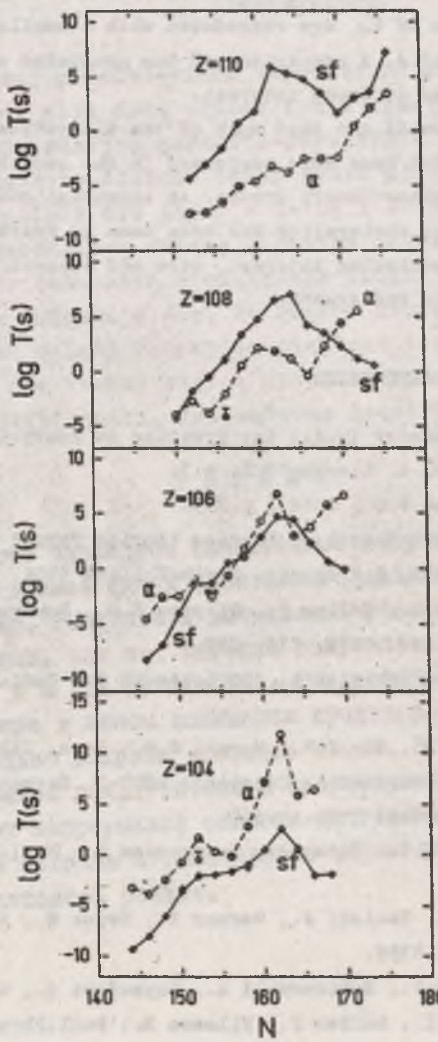

Fig.4. Logarithm of the calculated values of T_{α} and T_{sf} (open points) as compared with the experimental values (full points)

tuing an island separated from the peninsula by a region of deep instability, as believed earlier. This is qualitatively illustrated in fig.3.

The described results constitute a theoretical extrapolation. Thus, it is an open question how much one can rely on them. Still, in the experimental region, the calculated values of T_{sf} reproduce seven known lifetimes within a factor smaller than 2, on the average, i.e. very well. The three values of T_{α} are reproduced with a smaller accuracy. This is illustrated in fig.4. A comparison of the predicted values with future experiments will be of great interest.

Concluding, one should add that much of the theoretical studies of the half-lives described here were performed in the cooperation of the Lublin and Warsaw nuclear-theory groups. An essential contribution to the development of this cooperation has been done by Professor Stanisław Szpikowski. His continuing interest, care and support for it is basic for its existence and growth.

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STRESZCZENIE

W pracy przedstawiono współczesne obliczenia teoretyczne rozpadów alfa oraz czasów życia spontanicznego rozszczepienia najcięższych parzysto-parzystych jąder. Wyniki rachunków wskazują na dłuższe czasy życia niż dotychczas otrzymywane, szczególnie dla jąder o Z=108 i N=164. Rezultaty te wprowadzają jakościową zmianę w naszym pojmowaniu zakresów ciężkich jąder atomowych o względnie długim czasie życia. W szczególności, wnioskuje się, że region hipotetycznych superciężkich jąder należy raczej do ciągłego obszaru długożyciowych jąder, a nie tworzy osobną wyspę odseparowaną obszarem głębokiej niestabilności, jak sądzono dawniej.

Р Е З Ю М Е

В работе приведены современные теоретические расчеты α-распадов и времен жизни спонтанного деления самых тяжелых четно-четных ядер. Результаты вычислений указывают на более длинные времена жизни, чем те, которые получались до сих пор, особенно для ядер с N = 108 и N = 164. Эти результаты вносят качественное изменение в нашем понимании пределов тяжелых атомных ядер с относительно длинным временем жизни. В частности - сделан вывод, что район гипотетических сверхтяжелых ядер скорее всего принадлежит непрерывной области долгоживущих ядер и не образует отдельного острова ограниченного морем глубокой нестабильности, как это считалось раньше.