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MASSES AND HALF-LIVES OF SUPERHEAVY ELEMENTS*

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Spontaneous fission and α-decay half-lives of superheavy elements are determined in the macroscopic-microscopic model where the macroscopic part is the Lublin–Strasbourg Drop and the pairing correction is based on the state-dependent two-body interaction of the δ type. The coupling strengths of the pairing force are fitted to experimentally known masses of heavy nuclei with $Z \geq 98$.

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1. Introduction

In our previous work [1] we have shown that using the state-dependent pairing of *e.g.* δ-type instead of the seniority force has an influence on the fission barrier heights and on the systematics of mass parameters and yields spontaneous fission half-lives $T_{\rm sf}$ being closer to experimental data for most of the studied macroscopic models. Our previous calculations were performed only for even–even fermium isotopes. In the following we investigate a wider range of even–even and even–odd nuclei. Spontaneous fission half-lives are determined in the macroscopic–microscopic (M–M) model. We use the Lublin–Strasbourg Drop (LSD) [4] for the macroscopic part and the sixth order Strutinsky shell and pairing corrections are evaluated with single-particle spectra obtained with the Woods-Saxon potential and the *universal* set of parameters [2]. The intensities of the δ-force are adjusted to 48 masses of even–even, odd–even and odd–odd nuclei (with $Z \geq 98$) for which experimental data is known.

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2. Nuclear masses

The mass of a nucleus is a basic quantity from which other quantities, like α-decay energies (Q_α), can be determined. In our previous macroscopic-microscopic calculations we managed to reproduce the masses of about 600 rare-earth nuclei to a very good accuracy (rms=0.66 MeV) [3] using the Lublin–Strasbourg Drop formula and fitting only two pairing coupling strengths (one for protons and one for neutrons) for all the nuclei. In our calculations of the masses and $T_{\rm sf}$ of superheavy nuclei we consider the LSD model to be the best choice for the macroscopic part of the energy inasmuch as its parameters were fitted to all presently known nuclear masses and give a better accuracy for fission barriers as compared to other models [4]. The pairing interaction with the zero-range δ-force reads:

$$\hat{V}_{\rm pair} = V_{0\tau}\frac{1}{4}(1-\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2)\,\delta(\boldsymbol{r}_1-\boldsymbol{r}_2)\,, \qquad (1)$$

where $V_{0\tau}$ is the coupling constant for protons or neutrons. The pairing Hamiltonian eigenproblem is solved in the BCS approximation, in a truncated space containing N single-particle levels for neutrons and Z levels for protons. In the case of an odd number of nucleons of one type, the odd particle is treated through the blocking approach. The $V_{0\tau}$ parameters are fitted to reproduce experimentally known masses [5] of $Z=98$ to $Z=108$ nuclei. Since no particular dependence of the coupling constants on the proton or neutron number is observed, we assume constant pairing strengths in the whole region of considered nuclei: $V_{0\rm n}=220\,{\rm MeVfm}^3$ and $V_{0\rm p}=230\,{\rm MeVfm}^3$. Such average coupling parameters allow to reproduce the masses of 48 nuclei with a rms error equal to 0.68 MeV. However, it should be stressed that the experimental uncertainties for the masses in this region are relatively large, therefore the rms mass deviation depends considerably on these experimental errors. In Fig. 1 the discrepancies between the results of M–M calculations and experimental data, including predictions of Ref. [5], are shown for 258 nuclei with $Z\geq 98$.

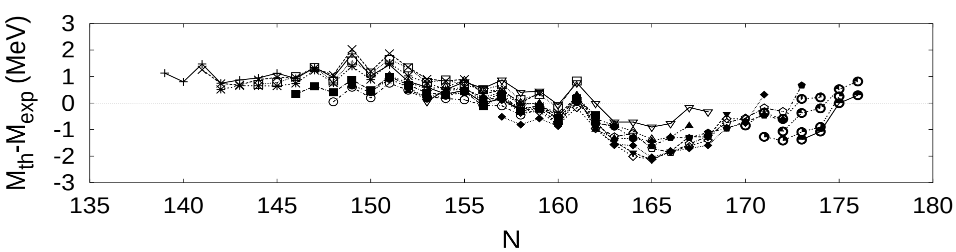

Fig. 1. Mass discrepancies between the results of M–M calculations and experimental data and estimates [5].

3. Spontaneous fission

Spontaneous fission half-lives of even–even (Z = 110–120) and odd–even (Z = 114) nuclei are examined in the framework of the macroscopic-microscopic method. The potential energy and the components of the inertia tensor (evaluated in the adiabatic cranking model) are determined on a three dimensional $\boldsymbol{\beta}$ deformation grid defined as follows: $\beta_2 = 0(0.05)1.2$, $\beta_4 = -0.12(0.04)0.32$ and $\beta_6 = -0.12(0.04)0.12$. Spontaneous fission half-lives $T_{\rm sf}$ are calculated within the WKB model as described *e.g.*, in Ref. [8] using a dynamical programming method, understood as a search for the trajectory which minimizes the action integral. Calculated spontaneous fission and α-decay half-lives (evaluated according to Ref. [6]) as well as experimental data [5] are shown in Fig. 2. It is seen that in our predictions most of the studied nuclei would prefer to decay through an α particle emission which is in agreement with the data compiled in Ref. [5]. However, in the last experiments done in Dubna [9] spontaneous fission of $Z = 110$ and 112 nuclei with $N \sim 170$ was observed. Experimental decay modes and half-lives measured recently [9] and the results of our calculations for Z = 110–118 isotopes are listed in Table I.

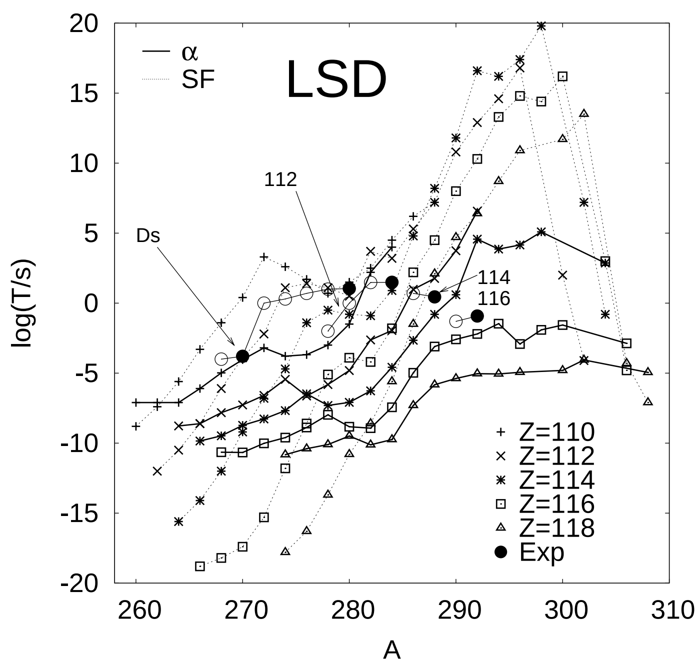

Fig. 2. The logarithms of the spontaneous fission (dashed lines) and α-decay (solid lines) half-lives of even–even superheavy nuclei as compared to experimental data (black circles) and estimates (open circles) [5].

TABLE I

Spontaneous fission and α-decay half-lives of superheavy nuclei. The first two columns correspond to the atomic number Z and the mass number A. The third column shows the experimentally known decay modes. Column four gives the total experimental half-life reported in Ref. [9]. The last two columns show the logarithms of the calculated half-lives (in seconds) for α-decay (T_α) and for spontaneous fission ($T_{\rm sf}$).

Z	A	Decay mode (%) [9]	$\log(T_{1/2}/s)$ [9]	$\log(T_{\rm sf}/s)$	$\log(T_\alpha/s)$
110	270	α100; sf0.2	−3.79	−0.39	−4.04
110	280	sf	1.04	−0.09	−1.49
112	282	sf	−3.3	0.56	−2.62
112	284	sf	−0.99	0.50	−1.95
114	286	α60; sf40	−0.79	0.68	−2.65
114	287	α	−0.29	1.06	0.86
114	288	α	−0.09	0.91	−0.79
114	289	α	0.43	1.06	1.72
116	290	α	−1.82	0.9	−2.58
116	292	α	−1.74	1.01	−2.20
118	294	α	−2.74	0.93	−5.05

In conclusion, it seems that the LSD model with the δ-pairing force is an appropriate method to describe simultaneously the masses and decay of the heaviest elements. However, in view of the fast progress in the production of superheavy nuclei and new experimental data still to come, more theoretical investigation is required to describe properly the properties of these nuclei and to understand the physics underlying experimental evidence.

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