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DESCRIPTION OF α-SPECTROSCOPIC DATA OF ODD-A SUPERHEAVY NUCLEI*

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α-decay chain of ^{271}Ds is studied theoretically within a macroscopic–microscopic approach. It is found that experimental α-transition energies are well reproduced by calculations. Rather small single-particle effects are obtained in these energies.

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1. Introduction

One observes recently a fast increase of spectroscopic data of superheavy nuclei. This is a result of intensive experimental studies of these nuclei. (*e.g.* [1–3]). The data comes almost exclusively from measurements of α-particle energies appearing in α-decay chains, mainly of odd-A nuclei. Gamma-spectroscopic studies, which are also intensive in recent years, are done for lighter nuclei (up to rutherfordium, $Z = 104$, *cf.* *e.g.* [4–7]) and only approach presently the region of superheavy nuclei.

Theoretical description of the data makes use of both macroscopic–microscopic (*e.g.* [8, 9]) and purely microscopic (*e.g.* [10–13]) approaches. In particular, in a recent paper [9], an extensive study of proton one quasi-particle spectra has been done within a macroscopic–microscopic model. Heavy and superheavy odd-Z, even-N nuclei with proton number $Z =$ 93–117 and neutron number $N =$ 136–178 have been considered.

The objective of the present paper is to learn how well an odd-A α-decay chain can be described within such a model. In particular, it is aimed to see how much the description of α energies, observed in the chain, may be

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improved by the knowledge of single-particle spectra of nuclei appearing in the chain. The study is done on the example of the even-Z, odd-N nucleus ^{271}Ds (^{271}110).

2. Method of the calculations

The calculations are done within a macroscopic–microscopic approach. The Yukawa-plus-exponential model is used for the macroscopic part of energy of a nucleus and the Strutinski shell correction, based on the Woods–Saxon single-particle potential, is taken for its microscopic part.

A large, 4-dimensional deformation space $\{\beta_\lambda\}$, $\lambda = 2, 4, 6, 8$, is used to obtain the equilibrium deformations β_λ^0 of a nucleus. The contribution of an odd nucleon, occupying a single-particle state $|\,\mu\rangle$, to energy of a nucleus is described by the one-quasiparticle energy $E_\mu = \sqrt{(e_\mu - \lambda)^2 + \varDelta^2}$. Here, e_μ is the energy of the odd nucleon in the state $|\,\mu\rangle$ and $\varDelta$ is the pairing-energy gap parameter, calculated in the BCS approximation. Pairing interaction of the monopole type, with the same strength parameters as in [14], is taken. No blocking is used. The calculations of one-quasiparticle energies E_μ are performed in the same way as in [9].

3. Results and discussion

Before calculating single-neutron spectra of superheavy nuclei, for which such spectra are not yet known experimentally, we test the calculations in the case of heavy nuclei, for which such spectra (at least few levels) are already known.

Fig. 1 shows a comparison between calculated and experimental single-neutron spectra of the nucleus ^{245}Cm. The experimental data is taken from [15]. At each energy level, the quantum characteristics (projection of the total spin on the symmetry axis, $\varOmega$, and parity, π, of the state) is given. (In the figure, as well as in the whole paper, we give the spin projection $\varOmega$ multiplied by 2, for simplicity of notation). Besides $\varOmega$ and π, also the Nilsson ("asymptotic") quantum numbers $[Nn_z\varLambda]$ are given, where N is the total number of the oscillator quanta, n_z is the number of quanta along the symmetry axis Oz and $\varLambda$ is the projection of the orbital angular momentum on the symmetry axis. One can see that the quantum characteristics, $\varOmega$ and π, of the ground state, obtained in experiment, are reproduced by the calculations. Also the sequence of the excited states is generally reproduced; only the state 9-[734] appears in a wrong place. The average discrepancy (rms) between the calculated and experimental excitation energies of six lowest states (which appear below 1 MeV) is 173 keV. (Average of absolute values of differences between calculated and experimental energies of these levels is 156 keV.)

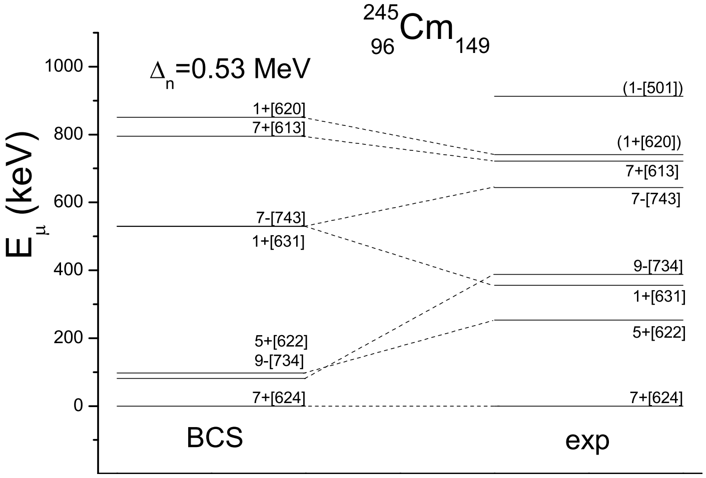

Fig. 1. Comparison between calculated (BCS) and experimental (exp) single-neutron spectra of the nucleus ^{245}Cm. Calculated neutron pairing-energy gap parameter Δ_n is also given.

Fig. 2 shows spectra of lowest energy levels of nuclei appearing in the α-decay chain of the nucleus ^{271}Ds. The spectra are calculated as a help to interpret the observed [16] α-decay energies in this chain, *i.e.* to say between which states of consecutive nuclei the decay occurs. A general assumption is that the α transitions occur between the states with the same structure (the same quantum numbers). If a transition to a higher excited state takes place, the most probable γ decays to a lower state are assumed to occur before the next α transition. Even with these assumptions, however, a number of different interpretations are possible. We show here one of them.

According to it, the first transition starts from a very low excited state 7+[613] of the nucleus ^{271}Ds and leads to the ground state 7+[613] of ^{267}Hs. The second one leads from this state to a low state 7+[613] of ^{263}Sg, which undergoes γ decay of the E2 type to a lower state 3+[622]. From this state, the third α transition leads to a very low state 3+[622] of ^{259}Rf, from which, the last α-decay leads to a low state 3+[622] of ^{255}No. One can see that, within this interpretation, energies $Q_\alpha^{\rm t}$ of the four α transitions are close to energies Q_α of the ground-state (g.s.) to ground-state transitions.

Calculated values of α-transition energies $Q_\alpha^{\rm t}$, and of α-decay (g.s. to g.s. transitions) energies Q_α are given in Table I and compared with experimental values $Q_\alpha^{\rm t,\,exp}$. Respective differences: $\Delta Q_\alpha^{\rm t} \equiv Q_\alpha^{\rm t,\,th} - Q_\alpha^{\rm t,\,exp}$, $\Delta Q_\alpha \equiv Q_\alpha^{\rm th} - Q_\alpha^{\rm t,exp}$ are also shown. In addition, a contribution ΔE of quasiparticle excitation energies to the α transition energy $Q_\alpha^{\rm t}$

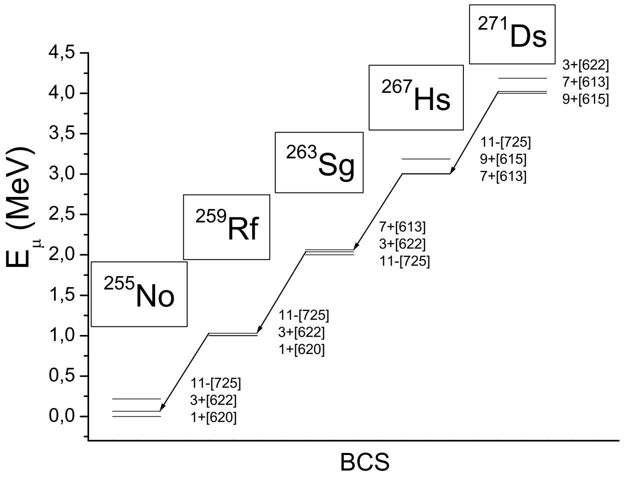

Fig. 2. One of possible interpretations of α-decay chain of the nucleus ^{271}Ds ($^{271}110$). Numbers at the vertical axis show only the scale in which qusiparticle excitation energies E_μ are drawn.

$$Q_\alpha^{\mathrm{t}} = Q_\alpha + (E_p - E_d) \equiv Q_\alpha + \mathit{\Delta} E, \tag{1}$$

is also given. Here, E_p and E_d are the excitation energies of the initial (parent nucleus) and final (daughter nucleus) states of the α transition, respectively. Theoretical values, Q_α^{th}, are taken from [17, 18] and experimental ones, $Q_\alpha^{\mathrm{t,\,exp}}$, from [16]. One can see in Table I that calculated α-decay energies Q_α^{th} are in a good agreement with measured α-transition energies $Q_\alpha^{\mathrm{t,\,exp}}$. The largest discrepancy is 0.28 MeV and the average one (rms) is 0.19 MeV. Single-particle effects ($\mathit{\Delta} E$) in Q_α^{t} are small (they do not exceed 60 keV) and, generally, they do not improve the agreement, at least within the considered interpretation of the chain.

TABLE I

α-transition energies Q_α^{t} (theoretical and experimental), calculated α-decay energy Q_α^{th} and quantities derived from them, described in the text.

Nucleus	$Q_\alpha^{\mathrm{t,\,th}}$ [MeV]	Q_α^{th} [MeV]	$Q_\alpha^{\mathrm{t,\,exp}}$ [MeV]	$\mathit{\Delta} Q_\alpha^{\mathrm{t}}$ [MeV]	$\mathit{\Delta} Q_\alpha$ [MeV]	$\mathit{\Delta} E$ [MeV]
^{271}Ds	11.09	11.07	10.91	0.18	0.16	0.02
^{267}Hs	9.69	9.75	10.03	−0.34	−0.28	−0.06
^{263}Sg	9.25	9.21	9.39	−0.14	−0.18	0.04
^{259}Rf	9.02	9.08	9.03	−0.01	0.05	−0.06

In conclusion, one can say the following:

(1) One-quasiparticle description of single-neutron states is rather good: it reproduces the ground state; also, the sequence of low excited states is generally reproduced.

(2) Experimental α-transition energies Q^{t}_{α} are well reproduced by calculated α-decay energies Q_{α}. Single-particle effects in Q^{t}_{α} are rather small and they generally do not improve the agreement.

As the conclusions are based, however, on a rather small number of considered nuclei, they should not be considered as general ones.

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