RECENT ADVANCES IN THEORETICAL STUDIES OF 2p RADIOACTIVITY: NUCLEAR MANY-BODY STRUCTURE IN THREE-BODY MODEL*

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(Received February 7, 2011)

Nowadays quantum-mechanical three-cluster theory allows one to reliably calculate the processes of 2p radioactivity (true three-body decays) and the corresponding energy and angular correlations. However, the connection of the three-cluster final state configuration with possibly many-body internal structure of the nucleus is unclear in this approach. A simple method for taking into account the many-body structure in the three-body decay calculations was developed. The results of the relativistic mean field (RMF) calculations are used as an input for the three-cluster decay model. The calculations for the prospective two-proton emitter ^{26}S are provided.

DOI:10.5506/APhysPolB.42.555
PACS numbers: 23.50.+z, 21.10.Tg, 21.10.Dr, 21.60.Gx

The ground state two-proton (2p) radioactivity was predicted by Goldansky in 1960 [1]. What he called *true two-proton decay* is a situation where the sequential emission of the particles is energetically prohibited and all the final-state fragments are emitted simultaneously. Since the experimental discovery of the ^{45}Fe two-proton radioactivity in 2002 [2, 3], the recent progress of this field is very fast. New cases of 2p radioactivity were found for ^{54}Zn [4], ^{19}Mg [5].

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* Presented at the Zakopane Conference on Nuclear Physics "Extremes of the Nuclear Landscape", August 30–September 5, 2010, Zakopane, Poland.
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The quantum-mechanical three-cluster theory of $2p$ radioactivity and three-body decay was developed in Refs. [6]. This approach is utilizing the hyperspherical harmonics method with approximate boundary conditions for the three-body Coulomb problem. Exploratory studies of correlations performed in [7] predicted complex correlation patterns which are sensitive to the structure of the $2p$ emitters. Confirmation of the predictions [7] were obtained in the studies of $2p$ decay in ^{6}Be [9], ^{19}Mg [5], and ^{45}Fe [8]. The three-cluster approach to the $2p$ decays is well justified for the closed-shell systems or systems with a closed-shell core. However, most of the two-proton emitters do not belong to this class, and important effects of the pairing correlations can be expected for them. As the next step, we need to establish closer correspondence between the three-cluster model results and many-body structure calculations.

The major components of the three-body cluster WFs with $J^\pi = 0^+$ can be written in a schematic spectroscopic notation as

$$\Psi_3^{(+)} = \sum\nolimits_i X_i \left[l_i^2\right]_0 , \qquad \sum\nolimits_i |X_i|^2 \lesssim 1 . \tag{1}$$

In Ref. [7], the results of the $2p$ width calculations were provided as functions of the weights of the main cluster configurations $w(l_i^2) = X_i^2$

$$\Gamma\left(\left\{X_i^2\right\}\right) = \frac{j\left(\left\{X_i^2\right\}\right)}{N} , \tag{2}$$

where N is a normalization in the internal region and j is outgoing flux. The values which can be put in correspondence with the components of the three-body WF (1), to take into account the many-body structure, are overlaps of the many-body WFs of the precursor-daughter pair multiplied by a combinatorial term. They can be written in the same spectroscopic notation as Eq. (1)

$$\Psi_{A,A-2} = \left(\frac{A!}{2!(A-2)!}\right)^{1/2} \langle \Psi_A | \Psi_{A-2} \rangle = \sum_i \tilde{X}_i \left[l_i^2\right]_0 . \tag{3}$$

The overlaps of Eq.(3) are, in general, not normalized to unity, $N_{2p} = \sum_i |\tilde{X}_i|^2 \neq 1$. If we normalize them, $\Psi_{A,A-2} \rightarrow \Psi_{A,A-2} N_{2p}^{-1/2}$, then the initial many-body WF becomes non-unitary $||\Psi_A|| = N_{2p}^{-1}$. According to Eq. (2), the width should be then renormalized as

$$\tilde{\Gamma} = N_{2p}\, \Gamma\left(\left\{\frac{\tilde{X}_i^2}{N_{2p}}\right\}\right) . \tag{4}$$

The renormalized width contains a product with structural factor (N_{2p}) which can be easily interpreted as a kind of a spectroscopic factor in analogy with the two-body decays. Contrary to the two-body case, the dependence of the width on the structure includes the dependence on the amplitudes $\{X_i\}$. They should be adjusted as $X_i \to \tilde{X}_i/\sqrt{N_{2p}}$. That makes the above renormalization a complicated non-linear procedure.

To calculate the amplitudes $\tilde{X}_i$ in a many-body approach, we can use a formalism analogous to the same intrinsic structure model as for direct two-nucleon transfer reactions [10, 11]. The structure part of the two-nucleon transfer cross-section is determined by the spectroscopic amplitude B

$$B^J_{(K_iK_f,kk')} = \sum_{MM_i} C^{J_fM_f}_{J_iM_iJM} \langle \Psi_{K_f} | \frac{1}{1+\delta_{(kk')}} \sum_{m_km_{k'}} C^{JM}_{j_km_kj_{k'}m_{k'}} a_k a_{k'} | \Psi_{K_i} \rangle \,.$$

For the ground states of both the parent and daughter nuclei we apply the BCS approximation:$|\Psi_K\rangle = \prod_{k>\,0} \left(u_{(k)} + v_{(k)} a^\dagger_k a^\dagger_{\bar{k}} \right) |-\rangle$, where $|-\rangle$ is the bare vacuum. The spectroscopic amplitude used in Eq. (3) takes the form

$$\tilde{X}_{(k)} = B^0_{(K_iK_f,kk)} = \sqrt{\left(j_k + \tfrac{1}{2}\right)}\, u^{(Z-2)}_{(k)} v^{(Z)}_{(k)} \,. \qquad (5)$$

The calculations are performed in the relativistic mean field approach [12].

The effect of the many-body structure on the results of the three-body calculations is demonstrated in Figs. 1 and 2 on the example of the prospective true $2p$ emitter ^{26}S. Important effects are found: only renormalization due to N_{2p} gives more then factor of 2 to the width compared to Hartree approximation. Details of these calculations and recent experimental results concerning ^{26}S can be found in Ref. [13].

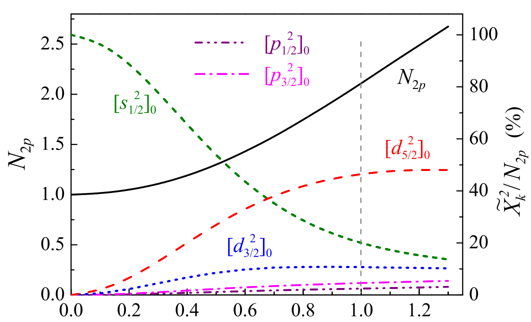

Fig. 1. Weights of the major components of the overlaps Eq. (3) (left axis) and the total overlap normalization as a function of the parameter α (right axis), scaling the pairing gap $\Delta \to \alpha\Delta$.

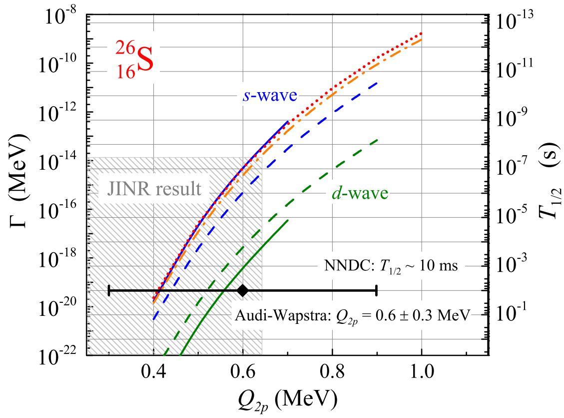

Fig. 2. Width of the ^{26}S g.s. as a function of the $2p$ decay energy. Solid and dashed curves correspond to the quasiclassical simultaneous emission model and to the three-body "l^2" model, respectively. The RMF-assisted three-body model, based on the relativistic Hartree and on the complete RH + BCS results are shown by the dotted and by the dash–dotted curves, respectively. The hatched area shows the ranges excluded by the recent experiment [13].

L.V.G. acknowledges the support from FAIR-Russia Research Center grant, Russian Foundation for Basic Research grants 08-02-00892, 08-02-00089-a, and the Ministry of Industry and Science grant NSh-7235.2010.2. E.V.L. acknowledges support by the Hessian LOEWE initiative through the Helmholtz International Center for FAIR.

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