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FRAGMENTATION OF ONE-QUASIPARTICLE STATES IN ^{153,155}Sm AND ^{153,155}Eu

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Fragmentation is calculated for neutron $2f_{7/2}$, $1h_{9/2}$, $1i_{13/2}$, $3p_{3/2}$, $2f_{5/2}$, $3p_{1/2}$, $2g_{9/2}$ and proton $1g_{7/2}$, $2d_{5/2}$, $1h_{11/2}$, $2d_{3/2}$, $3s_{1/2}$, $2f_{7/2}$ subshells providing a dominant contribution to the cross sections of (α, ^{3}He) and (α, t) reactions in the ^{152,154}Sm isotopes.

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

Фрагментация одноквазичастичных состояний в ^{153,155}Sm и ^{153,155}Eu

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Рассчитана фрагментация нейтронных подоболочек $2f_{7/2}$, $1h_{9/2}$, $1i_{13/2}$, $3p_{3/2}$, $2f_{5/2}$, $3p_{1/2}$, $2g_{9/2}$ и протонных подоболочек $1g_{7/2}$, $2d_{5/2}$, $1h_{11/2}$, $2d_{3/2}$, $3s_{1/2}$ и $2f_{7/2}$, которые дают подавляющий вклад в сечения (α, ^{3}He)- и (α, t)- реакций на изотопах ^{152,154}Sm.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

Fragmentation of one-quasiparticle states of deformed nuclei has theoretically been investigated within the quasiparticle-phonon nuclear model (QPNM) in refs./1-3/. The experimental information on fragmentation of these states is still scarce/4-6/. The study of the ^{152,154}Sm (α, ^{3}He) ^{153,155}Sm and ^{152,154}Sm (α, t) ^{153,155}Eu reactions has recently been undertaken in the Michigan University, USA. Therefore, it became necessary to calculate fragmentation of particle quasineutron states in ^{153,155}Sm and particle quasiproton states in ^{153,155}Eu. The results of calculations of fragmentation of some states in the above nuclei are the aim of the present paper.

The calculations have been performed in the QPNM with the ground and excited state wave functions of deformed odd-A nuclei in the form

$$\Psi_\nu(K^\pi) = \frac{1}{\sqrt{2}} \sum_{\sigma} \{ \sum_{\rho} C_\rho(K\nu)\, \alpha^+_{\rho\sigma} + \sum_{g} D_g(K\nu)(\alpha^+ Q^+)_g \} \Psi_0 \ , \qquad (1)$$

where Ψ_0 is the ground state wave function of the relevant doubly even nucleus, ν is the state number with momentum projection onto the symmetry axis K and parity π ,$g \equiv q\sigma\lambda\mu i$ (i is the root number of a secular equation for one-phonon states with multipolarity λ and projection μ), α^+ and Q^+ are the quasiparticle and phonon creation operators. The set of quantum numbers for a one-particle state is denoted by $q\sigma$ and for states with given value of K^π by $\rho\sigma$, $\sigma = \pm 1$.

The strength functions $C^2_\rho(\eta)$ describe the strength distribution of a certain one-quasiparticle state ρ over an odd-A nucleus spectrum and has the following form /1/

$$C^2_\rho(\eta) = \frac{1}{\pi} \operatorname{Im} \mathcal{F}^{-1}_\rho(\eta + i\Delta/2) . \qquad (2)$$

Here $\mathcal{F}_\rho(\eta_\nu) = 0$ is the secular equation for energies η_ν of states (1).

In some cases fragmentation of a spherical subshell $n\ell J$ over the states of a deformed nucleus proves to be interesting. Therefore, one should take into account the contribution of this subshell to many single-particle states of a deformed potential and their fragmentation (2) due to the interaction with phonons. Expansion of the single-particle state wave function $\phi_{\rho K}$ over shell functions $\phi_{n\ell J}$ of the spherical potential is

$$\phi_{\rho K} = \sum_{n\ell J} a^{\rho K}_{n\ell J} \phi_{n\ell J} . \qquad (3)$$

As a result, the relevant strength function $S_{n\ell J}(\eta)$ of the subshell $n\ell J$ fragmentation is /1-3,7/

$$S_{n\ell J}(\eta) = \frac{1}{\pi} \operatorname{Im} \sum_{\rho K} \frac{1}{\mathcal{F}_\rho(\eta + i\Delta/2)} \frac{\theta(a^{\rho K}_{n\ell J} ; \eta + i\Delta/2)}{\theta_\rho(\eta + i\Delta/2)} \approx \sum_{\rho K} (a^{\rho K}_{n\ell J})^2 C^2_\rho(\eta) . \qquad (4)$$

Here $\theta_\rho(\eta + i\Delta/2)$ and $\theta(a^{\rho K}_{n\ell J} ; \eta + i\Delta/2)$ are the determinants obtained from the basic determinant $\theta(\eta + i\Delta/2)$ by eliminating and adding rows and columns. The explicit form of the above determinants is given in refs. /1,3/ and /7/.

In a stripping reaction of the type (α , ^{3}He) or (α , t), to calculate the spectroscopic factors the "particle" part of the total strength function is separated, that is,

$$\tilde{S}_{n\ell J}(\eta) = \frac{1}{\pi}\,\mathrm{Im}\sum_{\rho K} \frac{1}{\mathcal{F}_\rho(\eta + i\Delta/2)} \frac{\theta(u_{\rho K}a^{\rho K}_{n\ell J};\eta + i\Delta/2)}{\theta_\rho(\eta + i\Delta/2)} \approx \sum_{\rho K}(u_{\rho K}a^{\rho K}_{n\ell J})^2 C^2_\rho(\eta). \quad (5)$$

Here $u_{\rho K}$ are the Bogolubov transformation coefficients.

In the present calculations the averaging parameter is $\Delta = 0.4$ MeV. The parameters of the Saxon-Woods potential have been chosen as for zone A = 155 /1,2/. The details of calculations and methods of fitting the parameters of multipole-multipole forces have been described in ref./1/.

The strength functions $\tilde{S}_{n\ell J}$ (5) were calculated for the neutron spherical subshells $2f_{7/2}$, $1h_{9/2}$, $1i_{13/2}$, $3p_{3/2}$, $2f_{5/2}$, $3p_{1/2}$ and $2g_{9/2}$ in ^{153,155}Sm, the proton spherical subshells $1g_{7/2}$, $2d_{5/2}$, $1h_{11/2}$, $2d_{3/2}$, $3s_{1/2}$ and $2f_{7/2}$ in ^{153,155}Eu, and the contribution $(u_{\rho K}a^{\rho K}_{n\ell J})^2 C^2_\rho(\eta)$ of single-particle states in the sum (5).

Part of these results for ^{155}Sm is presented in fig.1. Here and further in fig.2 the strength functions $\tilde{S}_{n\ell J}$ are denoted by solid lines. The contributions of certain single-particle states ρ (marked in the figures by the Nilsson notation) in $\tilde{S}_{n\ell J}$ are shown as well.

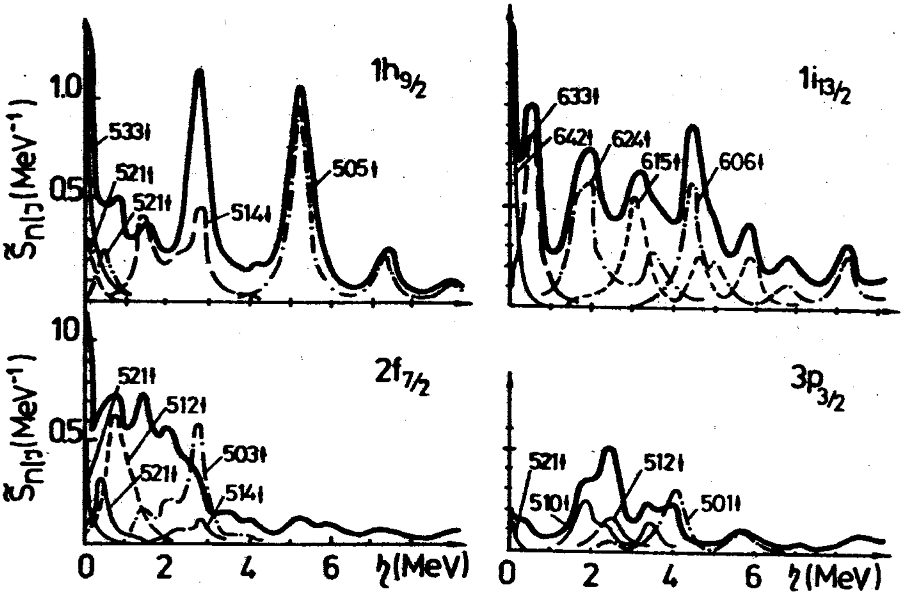

Fig.1. Fragmentation of neutron subshells in ^{155}Sm.

In the single-particle neutron scheme the $1i_{13/2}$ and $3p_{3/2}$ subshells are high-lying and the $2f_{7/2}$ subshell is close to the Fermi surface. Therefore, fragmentation of the $1i_{13/2}$ and $3p_{3/2}$ subshells is stronger than of $2f_{7/2}$; this can be seen from fig.1. About 36% of the $1i_{13/2}$ subshell strength and ~60% of the $2f_{7/2}$ subshell strength is concentrated in the interval up to 2 MeV. In the excitation energy interval up to 13 MeV about two third of the $1h_{9/2}$ and $2f_{7/2}$ subshell strength is assigned to particle states excited in the (α, ^{3}He) reaction; for the $1i_{13/2}$, $2g_{9/2}$ and $3p_{3/2}$ subshells this portion increases up to 3/4 and for the $2f_{5/2}$ and $3p_{1/2}$ subshells more than 4/5. The results of calculations for ^{153}Sm differ slightly from those for ^{155}Sm. The largest discrepancy occurs for the low-lying states and especially for $5/2^+[642\uparrow]$ and $3/2^-[521\uparrow]$

The high-lying neutron $2g_{9/2}$ subshell is most strongly fragmented (almost uniformly) in a wide energy interval higher than 13 MeV. It is obvious that the contribution of this subshell would hardly be extracted experimentally from the total cross section of the stripping (α, ^{3}He) reaction. In spite of the fact that on the whole fragmentation of the high-lying $2f_{5/2}$ and $3p_{1/2}$ subshells is considerable, one can note the strength concentration of individual single-particle states $5/2^-[503\downarrow]$, $1/2^-[521\downarrow]$ and $1/2^-[501\downarrow]$ in narrow excitation energy intervals 5-6 MeV, 0-1 MeV and 4-5 MeV, that should be seen experimentally.

Part of the results of calculations for ^{155}Eu is shown in fig.2. In the single-particle proton scheme the $2d_{5/2}$, $1g_{7/2}$ and $1h_{11/2}$ subshells are close to the Fermi surface and the $2d_{3/2}$ subshell is much farther. This leads to a different fragmentation of the above subshells, that is seen from fig.2. It should also be noted that the contributions to the strength functions of individual single-particle states are as a rule strongly mixed, which should be observed experimentally. About 1/2 of the $1g_{7/2}$ subshell strength, 2/3 of the $1h_{11/2}$ and $2d_{5/2}$ subshell strength and the dominant part of the $3s_{1/2}$, $2f_{7/2}$ and $2d_{3/2}$ subshell strength is attributed to particle states observed in the (α , t) reaction. Among the subshells high-lying in energy the $3s_{1/2}$ and $2f_{7/2}$ subshells are most strongly fragmented in a wide energy interval more than 8-10 MeV.

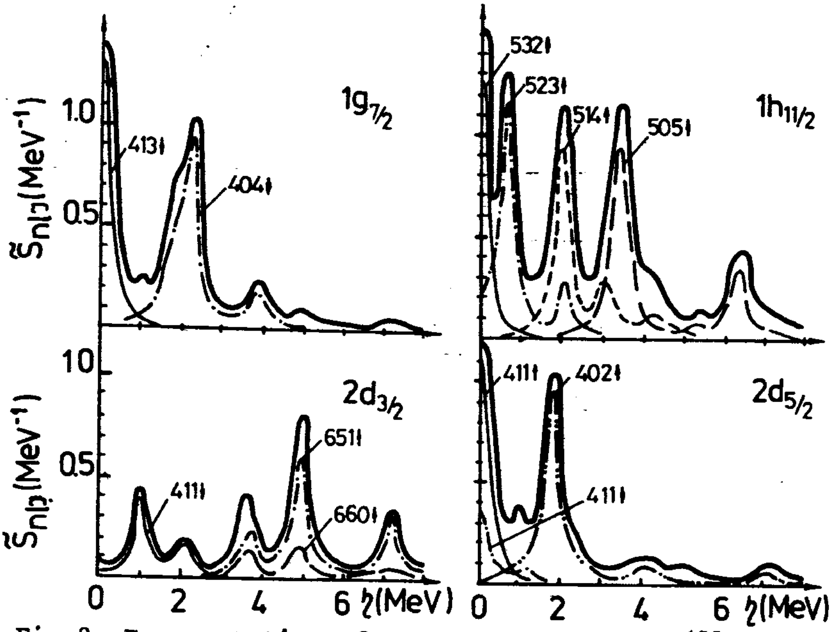

Fig.2. Fragmentation of proton subshells in ^{155}Eu.

It is seen from the calculations that the neutron subshells $1i_{13/2}$, $1h_{9/2}$ and $2f_{7/2}$ give the main contribution to the spectroscopic factors of the (α, ^{3}He) reaction; and the proton subshells $1h_{11/2}$, $2d_{5/2}$ and $1g_{7/2}$, to the (α, t) reaction in ^{152,154}Sm.

At present, the particle states with an energy less than 1 MeV are experimentally known in the ^{153,155}Sm and ^{153,155}Eu isotopes. Therefore, it is of interest to pass to higher excitation energies for elucidating the specific features of fragmentation of the states calculated in this paper.

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