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DAMPING OF SPHERICAL SUBSHELLS IN THE ^{239}U AND ^{237}Np NUCLEI

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In recent years a great attention has been paid to the study of the fragmentation of the simplest nuclear excitations over many nuclear levels at intermediate and high excitation energies. It is well-known that the fragmentation of few-quasiparticle states plays an important role in the defining many physically observable quantities such as the spreading width of giant resonances, the E1 - and M1 -radiative strength functions, the neutron strength functions, etc. That is why the study of this phenomenon has raised much interest of both experimenters and theoreticians. The effective tool for the experimental investigation of the one-quasiparticle state fragmentation in odd-mass nuclei is the one-nucleon transfer reaction. In the stripping reactions of the (d,p) -type the particle states are populated, and in the pick-up reactions of the (d,t) -type one can observe the hole strengths.

During the last time the fragmentation of few-quasiparticle components of the wave functions of nuclei is extensively studied in the frame-work of the quasiparticle-phonon nuclear model [1,2]. To describe the process of fragmentation this model suggests to employ the mechanism of the interaction of quasiparticles with phonons which are very important in the study of the structure of low-lying nonrotational states of atomic nuclei. Within the model, in ref. [3] there have been established the general regularities of the fragmentation of single-particle states in deformed nuclei which show that the fragmentation essentially depends on the position, quantum numbers of the single-particle state and on the characteristics of collective excitations. In ref. [4] the dependence of fragmentation upon the nuclear shapes is investigated. It is shown that, as a result, subshells with orbital momenta $\ell \geq 2$ in deformed nuclei are fragmented stronger than in spherical ones. In ref. [5] the fragmentation of various subshells in the rare-earth nuclei is calculated. The calculated picture of the strength distributions is in satisfactory agreement with the typical behaviour of the cross section of nucleon transfer reactions for this region of nuclei. In ref. [6] the fragmentation of low-spin single-particle negative parity states in the isotopes of tungsten are investigated. The model describes rather well some observed anomaly in the cross sections of (d,p) reactions in these nuclei using a futher small limitation on the size of the hexadecapole deformation of both the neutron and proton schemes.

In the present paper we study the damping of several high-lying and low-lying neutron subshells such as $3p_{3/2}$, $1i_{11/2}$ and $2g_{7/2}$, $1j_{15/2}$ in the ^{239}U. We also calculate the fragmentation of a large number of proton subshells in the ^{237}Np nucleus.

The model and methods for solving its main equations were described in ref. [3]. In this paper we write out only the formulae required for the understanding of the obtained results. In ref. [3] it was shown that the fragmentation of one-quasiparticle states in deformed nuclei may be studied within a simplified model. The wave function of the nonrotational state with the angular momentum projection into the nucleus symmetry axis K and parity π of an odd-A deformed nucleus has the form:

$$\Psi_i(K^\pi) = \frac{1}{\sqrt{2}} \sum_\sigma \{ \sum_\rho C^i_\rho a^+_{\rho\sigma} + \sum_g D^i_g (a^+ Q^+)_g \} \Psi_0, \qquad (1)$$

where Ψ_0 is the wave function of the ground state of a doubly even nucleus having one nucleon less than the studied one; i is the number of the state, $g \equiv \nu\lambda\mu j$, j being the number of the root of the secular equation for the one-phonon state of multipolarity $\lambda\mu$. The set of quantum numbers for any single-particle state is denoted by $(\nu\sigma)$ and for states with fixed K^π by $(\rho\sigma)$ with $\sigma = \pm 1$. The wave function (1) is normalized to unity. The structure of one-phonon states is calculated in the RPA. The quantity $(C^i_\rho)^2$ is determined from the wave function normalization (1). The secular equation for defining the energies η_i symbolically can be written as

$$F_\rho(\eta_i) = 0. \qquad (2)$$

To describe highly excited states within the model the phonons of multipole-type with $\lambda = 1, \ldots, 7$ as well as a large number of phonons of each multipolarity are taken into account. Alongside with the known low-lying collective quadrupole and octupole phonons we consider many weakly collectivized phonons as well as high-lying phonons like the giant resonances. The phonon space of the model is large enough and the good description of the density of highly excited states [7] proves its completeness.

We determine the single-particle fragmentation in deformed nuclei using the direct calculational method of averaged characteristics without a detailed calculation of each individual state. Following refs. [3], we construct the strength function of the energy distribution of the one-quasiparticle state ρ in the form

$$C^2_\rho(\eta) = \sum_i (C^i_\rho)^2 \rho(\eta_i - \eta) \qquad (3)$$

averaged with the weight

$$\rho(\eta_i - \eta) = \frac{1}{2\pi} \frac{\Delta}{(\eta_i - \eta)^2 + (\Delta/2)^2}. \qquad (4)$$

The energy interval of averaging Δ specifies the type of representation of calculational results. The choice of Δ is discussed in ref. [3]; here we take $\Delta = 0.4$ MeV. One can write (3) in the form [3]:

$$C^2_\rho(\eta) = \frac{1}{\pi} \mathrm{Im} \{ \frac{1}{F_\rho(\eta + i\Delta/2)} \}. \qquad (5)$$

In the simplified model the function $C^2_\rho(\eta)$ has the following form:

$$C^2_\rho(\eta) = \frac{\Delta}{2\pi} \frac{\Gamma(\eta)}{(\epsilon(\rho) - \gamma(\eta) - \eta)^2 + (\Delta/2)^2 \Gamma^2(\eta)}, \qquad (6)$$

where $\epsilon(\rho)$ is the energy of the one-quasiparticle state ρ and

$$\Gamma(\eta) = 1 + \sum_g \frac{\Gamma^2_{\rho g}}{(p(g) - \eta)^2 + (\Delta/2)^2}, \qquad (7)$$

$$\gamma(\eta) = \sum_g \frac{\Gamma^2_{\rho g}(p(g) - \eta)}{(p(g) - \eta)^2 - (\Delta/2)^2}. \qquad (8)$$

Here $p(g) = \epsilon(\nu) + \omega_{\lambda\mu j}$ is the energy of the quasiparticle ⊗ phonon state, $\Gamma_{\rho g}$ defines the interaction of states ρ and ν through phonon $\lambda\mu j$.

With the strength distribution of the single-particle state $C^2_\rho(\eta)$ we can now calculate the fragmentation of the spherical subshell denoted by the quantum numbers $n\ell j$ over many nuclear levels in a deformed nucleus. It is known that the static deformation results in a splitting of the subshell $n\ell j$ on $j + 1/2$ sublevels with the momentum projections into the nuclear symmetry axis $K = 1/2, 3/2, \ldots, j$. The subshell strength is spread over many single-particle states with different K. Every single-particle state ρ comes in this distribution with the weight determined by the expansion coefficient $a^{\rho K}_{n\ell j}$ of the single-particle state wave function $\Phi_{\rho K}$ of the axial-symmetric

Saxon-Woods potential in the shell functions $\Phi_{n\ell j}$ of spherical-symmetric potential

$$\Phi_{\rho K} = \sum_{n\ell j} a^{\rho K}_{n\ell j} \Phi_{n\ell j} . \qquad (9)$$

Thus, the subshell $n\ell j$ strength comprises all these state strengths taking into account their fragmentation due to the interaction with phonons. The subshell strength function has the form /4/ :

$$S_{n\ell j}(\eta) = \sum_{\rho K} (a^{\rho K}_{n\ell j})^2 C^2_\rho(\eta) \qquad (10)$$

with the normalization condition of type

$$\sum_{\rho K} (a^{\rho K}_{n\ell j})^2 = j + \frac{1}{2} . \qquad (11)$$

To compare with the spectroscopic data obtained in experiments in spite of $S_{n\ell j}(\eta)$ one must use for the reactions of (d,t)-type

$$\tilde{S}_{n\ell j}(\eta) = \sum_{\rho K} (a^{\rho K}_{n\ell j})^2 v^2_\rho C^2_\rho(\eta) \qquad (12)$$

and for the reactions of (d,p)-type

$$\approx{S}_{n\ell j}(\eta) = \sum_{\rho K} (a^{\rho K}_{n\ell j})^2 u^2_\rho C^2_\rho(\eta) , \qquad (13)$$

where u_ρ and v_ρ are the Bogolubov transformation coefficients. It is obvious that

$$S_{n\ell j}(\eta) = \tilde{S}_{n\ell j}(\eta) + \approx{S}_{n\ell j}(\eta). \qquad (14)$$

In numerical calculations we use the single-particle energies and wave functions of the axial-symmetric Saxon-Woods potential. The potential parameters, pairing the multipole-multipole interaction constants, and phonon number are taken from refs. /2,3/ . We have calculated the fragmentations of the $1i_{11/2}$ -, $1j_{15/2}$ -, $3p_{3/2}$ - and $2g_{7/2}$ -neutron subshells in the ^{239}U nucleus. We investigated the same problem for several proton subshells in the ^{237}Np nucleus. The particle and the hole strength functions are obtained for some of these subshells.

We show the strength functions $S_{n\ell j}(\eta)$ for the high-lying neutron subshells $2g_{7/2}$ and $3p_{3/2}$ in fig.1 and the strength functions $S_{n\ell j}(\eta)$ for the low-lying neutron subshells $1i_{11/2}$

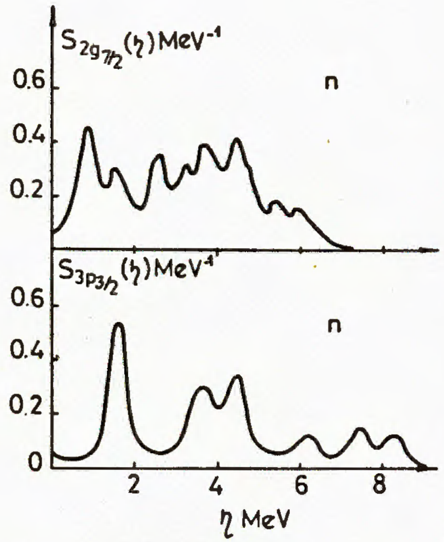

Fig. 1. Fragmentation of the $2g_{7/2}$ *- and* $3p_{3/2}$ *-subshells in the* ^{239}U *nucleus.*

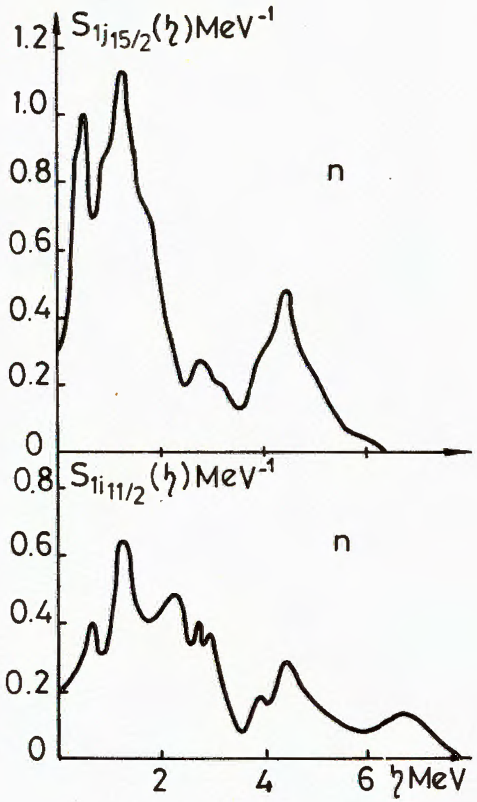

Fig. 2. Fragmentation of the $1j_{15/2}$ *- and* $1i_{11/2}$ *-subshells in the* ^{239}U *nucleus.*

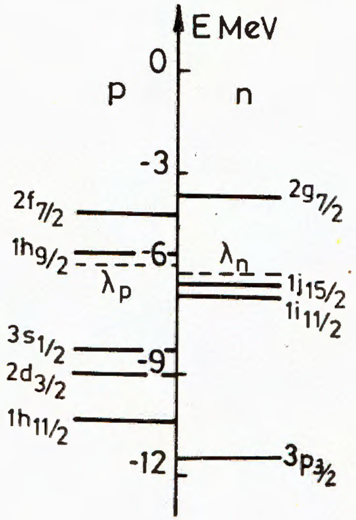

Fig. 3. The relative positions of subshells in the neutron and the proton schemes of the region of A = 239. The λ_n *and* λ_p *are the Fermi surface in the neutron and the proton schemes.*

and $1j_{15/2}$ in fig.2. Figure 1 shows that the strength distribution of $2g_{7/2}$ - and $3p_{3/2}$ -subshells inside their strength location regions is rather uniform, i.e., the distribution is characterised by a large second moment. The strength location region of $2g_{7/2}$ -subshell amounts to 7 MeV whereas such a quantity for the $3p_{3/2}$ -subshell has the range of ~ 9 MeV. Thus, the $3p_{3/2}$ -subshell is said to be fragmented stronger than the $2g_{7/2}$ -subshell. In fig.2 it is easily seen that the $1i_{11/2}$ -subshell fragments stronger than the $1j_{15/2}$ one (the location region of strength for $1i_{11/2}$ -subshell amounts to 8 MeV, and for the $1j_{15/2}$ to ~ 6 MeV only). Figure 2 shows an interacting feature: the strength distribution of these subshells is characterised by a big concentration of strength in the low region of the excitation energies. Thus, almost 40% of the total strength of $1i_{11/2}$ -subshell and up to 50% of the total $1j_{15/2}$ -strength are exhausted in the region of ≤ 2 MeV of excitation energies, whereas, it is clear from fig.1, only ~ 20% of the total strength for the $3p_{3/2}$ - and up to 30% for the $2g_{7/2}$ -subshells is in the same region of excitation energies.

Such a behaviour of the distribution of high-lying and low-lying subshells strength may be easily understood on the bases of the general regularities of fragmentation of single-particle states in deformed nuclei. In fig.3, we present the calculated relative positions of subshells to the Fermi level in the ^{239}U nucleus (in the right-hand side of energy axis) and in the ^{237}Np nucleus (in the left part of fig.3). Our calculations show that, as a result, the high-lying subshells, such as $2g_{7/2}$, $3p_{3/2}$ of the neutron scheme and $2f_{7/2}$, $2d_{3/2}$, $1h_{11/2}$ of the proton scheme, concentrate their strength mainly in some (2 or 3) single-particle states lying far from the fermi level. At the same time the low-lying subshells such as $1j_{15/2}$, $1i_{11/2}$ of the neutron scheme and $1h_{9/2}$ of the proton scheme have their strength concentrating in several (4 or 5) states lying close to the Fermi level. According to the general regularities of fragmentation of single-particle states in deformed nuclei, the farther the state is from the Fermi level the stronger it fragments. That is why such a behaviour of subshell strength distributions is observed in figs.1 and 2.

We present in figs.4 and 5 the strength functions $S_{n\ell j}(\eta)$ for the $1h_{9/2}$ - and $2f_{7/2}$ -subshells in the ^{237}Np nucleus. The $2f_{7/2}$ -subshell is the high-lying and the $1h_{9/2}$ -subshell is the low-lying ones. It is clear that the $2f_{7/2}$ -subshell is fragmented stronger than the $1h_{9/2}$.

At the end we show our calculated results for the spectroscopic factors $\tilde{S}_{n\ell j}(\eta)$ for several subshells in the ^{239}U and ^{237}Np nuclei in the table. These spectroscopic factors may be experimentally obtained in the nucleon transfer reactions of (d,t) -type. We should like to note that, as it is easily seen

Table

The spectroscopic factors $\tilde{S}_{n\ell j}$ for subshells

Nucleus	$n\ell j$	ΔE_x, MeV		
		0 ÷ 4	4 ÷ 8	8 ÷ 12
^{239}U	$2g_{7/2}$	0.31	0.19	-
	$3p_{3/2}$	0.80	0.59	0.31
	$1j_{15/2}$	2.24	0.75	-
	$1i_{11/2}$	1.82	0.44	-
^{237}Np	$3s_{1/2}$	0.63	0.16	-
	$2d_{3/2}$	1.21	0.21	0.17
	$1h_{11/2}$	2.17	2.36	0.69

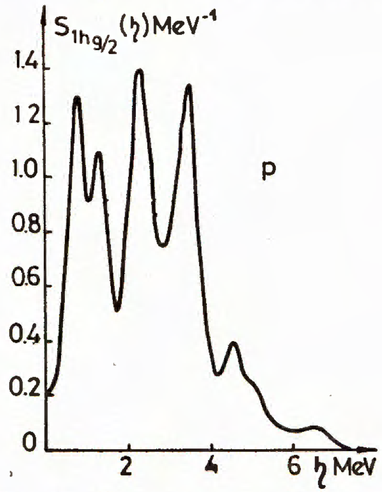

Fig.4. The fragmentation of the $1h_{9/2}$ -subshell in the ^{237}Np nucleus.

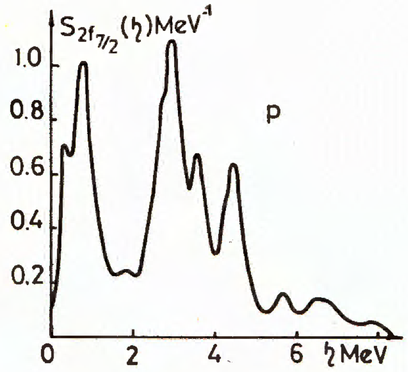

Fig.5. The fragmentation of the $2f_{7/2}$ -subshell in the ^{237}Np nucleus.

from (12), factor v^2_ρ leads up to excluding the contributions of the particle states in the function $\tilde{S}_{n\ell j}(\eta)$. These states manifest themselves in the $\tilde{S}_{n\ell j}(\eta)$ -functions. Thus, to observe the total strength of the $n\ell j$ -subshell it is necessary to use not only the (d,t)-reaction but also the (d,p)-reaction.

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Нгуен Динь Винь E4-85-446
Затухание сферических подоболочек в ядрах ^{239}U и ^{237}Np

В рамках квазичастично-фононной модели ядра расчитана фрагментация ряда нейтронных и протонных высоколежащих и низколежащих подоболочек в ядрах ^{239}U и ^{237}Np. Рассчитаны спектроскопические факторы для этих подоболочек, которые могут быть получены в реакции нуклонных передач типа (d,t).

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Nguyen Dinh Vinh E4-85-446
Damping of Spherical Subshells in the ^{239}U and ^{237}Np Nuclei

The fragmentation of several neutron and proton high-lying and low-lying subshells in the ^{239}U and ^{237}Np nuclei is calculated within the quasiparticle-phonon nuclear model. The spectroscopic factor for these subshells are obtained. They may be observed in the nucleon transfer reactions of the (d,t)-type.

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

Communication of the Joint Institute for Nuclear Research. Dubna 1985