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The aim of the present note is to attract attention of experimenters to the necessity of searching for two-phonon states in even-even deformed nuclei.

In spherical even-even nuclei a large number of quadrupole two-phonon states have been discovered, while in deformed nuclei there is only one rather reliable evidence /1/ for the existence of a two-phonon state in ^{154}Gd . The physical nature of the vibrational states in spherical and deformed nuclei is the same and the existence of two-phonon states in deformed nuclei call no doubts. Such a large difference in the information on the two-phonon states is due to the particularities of the spectra of spherical and deformed nuclei. The two-phonon states in spherical nuclei lie lower than the two-quasiparticle states and as a rule at such excitations at which there are no other levels. In deformed even-even nuclei the energies of the two-phonon states must be somewhat higher than those in spherical nuclei and, what is most important, they must be somewhat higher than those of the lowest two-quasiparticle states. The energies of the lowest two-phonon states are (1.5-2.5) MeV. At these energies in even-even deformed nuclei one observes, in addition to a large number of rotational levels, the two-quasiparticle states and the first and the second quadrupole $K^\pi = 0^+$ and 2^+ and the octupole $K^\pi = 0^-, 1^-, 2^-$ states . A complicated character of the spectra of the excited states of even-even deformed nuclei masks the two-phonon states.

We denote the two-phonon state by $K^{\pi}(\lambda\mu i)(\lambda'\mu' i')$, i.e. we express it in terms of the characteristics of the phonons entering this state, here λ is the phonon multipolarity, μ is the projection, i stands for the number of the secular equation root. The most characteristic feature of the two-phonon states is the enhanced gamma transition to the one-phonon states and to their rotational bands. To find, e.g. the two-phonon $K^{\pi} = 2^{+}$ or $K^{\pi} = 2^{-}$ states it is possible to use the fact that for them the B(E2) or B(E3) values for transitions to the one-phonon states are much larger than those for transitions to the rotational band of the ground state.

From the point of view of the microscopic structure the wave functions of the two-phonon states are superpositions of the four-quasiparticle states of three types (4n), (4p) and (2n, 2p) when the four quasiparticles are neutrons or protons or two quasiparticles are neutrons and two others are protons. The two-phonon $(\lambda\mu i)$ $(\lambda'\mu' i')$ states have two components, one of them with $K = |\mu - \mu'|$, the other with $K = \mu + \mu'$. It is interesting to find the splitting energy of these two states.

In ref.[2] it is shown that the lowest two-phonon states in strongly deformed even-even nuclei contain small admixtures of the one-phonon states. The most pure must be the two-phonon $K^{\pi} = 1^{+}, 3^{+}$ $4^{-}, 4^{+}$ states and others. The energies of such states are apparently close to the sum of the energies of the phonons which these states consist of. Due to small anharmonicity of the one-phonon vibrations the splitting energy of the lowest two-phonon states in deformed nuclei must be lower as compared with spherical nuclei. With increasing excitation energy the structure of the deformed nucleus states becomes more and more complicated[3] which leads to the appearance of admixtures in the two-phonon states.

The two-phonon states may be populated in beta decays. The matrix element, e.g. for β^{+} decay from the odd-odd nucleus state which is characterized by the quantum numbers s_0 , ν_0 with $K_{0,0} = K_{s_0} + K_{\nu_0}$ to the two-phonon state $(\lambda\mu i)(\lambda'\mu' i')$ is of the form

$$M\left(\begin{matrix} z-1\to z \\ N+1\to N\end{matrix}; s_0+\nu_0\right)=\frac{1}{\sqrt{2}}\sum_{s\nu} U_s V_\nu \{ <s+|\Gamma|\nu-> (\Psi^{\lambda\mu i}_{ss_0} \Psi^{\lambda'\mu' i'}_{\nu\nu_0} +$$

$$+ \Psi^{\lambda'\mu' i'}_{ss_0} \Psi^{\lambda\mu i}_{\nu\nu_0} + \bar{\Psi}^{\lambda\mu i}_{ss_0} \bar{\Psi}^{\lambda'\mu' i'}_{\nu\nu_0} + \bar{\Psi}^{\lambda'\mu' i'}_{ss_0} \bar{\Psi}^{\lambda\mu i}_{\nu\nu_0}) + \qquad (1)$$

$$+ <s+|\Gamma|\nu+> (\Psi^{\lambda\mu i}_{ss_0} \bar{\Psi}^{\lambda'\mu' i'}_{\nu\nu_0} + \Psi^{\lambda'\mu' i'}_{ss_0} \bar{\Psi}^{\lambda\mu i}_{\nu\nu_0} + \bar{\Psi}^{\lambda\mu i}_{ss_0} \Psi^{\lambda'\mu' i'}_{\nu\nu_0} + \bar{\Psi}^{\lambda'\mu' i'}_{ss_0} \Psi^{\lambda\mu i}_{\nu\nu_0}) \},$$

were $<s+|\Gamma|\nu\pm>$ is the one-particle matrix element of beta transition, s denotes the quantum numbers of one-particle neutron states, ν denotes those of proton states, the functions $\Psi^{\lambda\mu i}_{ss_0}$, $\bar{\Psi}^{\lambda\mu i}_{ss_0}$ are the coefficients for the expansion of the wave function of the one-phonon states in the two-quasiparticle states (they are tabulated in ref.[4]), V_s^2 is the pair density in the state denoted by s, $U_s^2=1-V_s^2$. All the notations are given in ref.[5]. In the case $K_{0,\bar{0}}=K_{s_0}-K_{\nu_0}$ in (1) $<s+|\Gamma|->$ and $<s+|\Gamma|\nu+>$ exchange their places, in the case of β^- decay the quantities $U_s V_\nu$ are replaced by $U_\nu V_s$. The numerical estimates made by eq. (1) show that in the majority of cases the reduced probabilities of beta transitions to the two-phonon states are hindered by one-two orders as compared to beta transitions (of the same type) between one-quasiparticle states. In some cases this hindrance may be even smaller.

Let us consider, e.g. the beta decay of ^{164}Tb from the $K^\pi=5^+$ p411↑+n633↑ state to the $K^\pi=4^-$ state in ^{164}Dy for which, according to[6], $\log ft = 6.2$. If the $K^\pi=4^-$ state is treated as two-phonon (221)(321) state then a beta transition can occur to a number of components including the component n633↑ −n521↑ + p411↑ + p411↓. We estimate the matrix element for the transition to this component. It follows from (1) that

$$M=\frac{1}{\sqrt{2}} V_{n521\uparrow} U_{p411\uparrow} < n521\uparrow|\Gamma|p411\uparrow > \bar{\Psi}^{221}_{p411\uparrow+p411\downarrow} \Psi^{321}_{n633\uparrow-n521\uparrow}.$$

According to ref./4/ $\bar{\Psi}^{221}_{p\,411\uparrow + p\,411\downarrow} = 0.87$, $\Psi^{321}_{n\,633\downarrow - n\,521\downarrow} = 0.3$ and $V^2_{n\,521\downarrow} = 0.83$, $U^2_{p\,411\downarrow} = 0.84$ therefore $M_1 \approx \langle n\,521\uparrow|\Gamma|\,p\,411\uparrow\rangle$ 0.2 . Taking into account the fact that in beta decays to one-particle levels which are near the Fermi surface U^2_s and V^2_s are close to 0.5 and that the beta decay goes also to other four-quasiparticle components we find that the beta decay to the two-phonon 4^- state in ^{164}Dy is hindered by about a factor of 5 as compared with the decay between the one-particle $n\,521\downarrow$ and $p\,411\uparrow$ states.

It is necessary to analyse the available experimental data in order to find out the two-phonon states. So, the two-phonon (1.5-2.0) MeV states must be in the following even-even nuclei : the (221)(221) states in the isotopes of dysprosium, erbium and in ^{168}Yb ; the (221) (201) states in the isotopes of gadolinium, dysprosium and in ^{164}Er , the (221) (321) states in the dysprosium isotopes, the (201) (301) states in the isotopes of thorium, uranium and plutonium and so on. Apparently among the $K^{\pi} = 4^+$ states in ^{158}Dy , ^{160}Dy populated in beta decays of ^{158}Ho /7/ and ^{160}Ho /8/ there are two-phonon states.

Experimental discovery of the two-phonon states, determination of the splitting energy, clearing up of the admixtures and so on are of great interest in studying the structure of deformed nuclei.

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