Level density and radiative strength functions of dipole $\gamma$-transitions in $^{163}$Dy

V.A. Khitrov, Li Chol, A.M. Sukhovoj

Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Physics, 141980, Dubna, Russia

In the report [1] presented at the 11-th Symposium “Capture Gamma-Ray Spectroscopy”, intensities of the two-step cascades in $^{163}$Dy measured in Rež were reproduced with involving the idea of ”scissors mode” built on the head-states with different structure of their wave functions. From the comparison of the experimental data and calculated spectra (distorted by the random fluctuations of the widths), the authors conclude about the significant influence of this specific excitations on the cascade $\gamma$-decay process.

There are some doubts about this result for the following reasons: $^{163}$Dy is the well deformed nucleus with rather strong quadrupole deformation. The spectrum of the excited states, structure of their wave functions and matrix elements of the transitions between them in such nuclei are well enough described in the framework of quasiparticle-phonon model of nucleus [2] with taking into account only quasi-particle excitations, quadrupole and octupole phonons. The notion of significant influence of the “scissors mode” on the mentioned nuclear parameters is not used in this approach. Moreover, analysis [3] of the averaged intensities of cascades exciting both known “scissors mode” and states of other type that the cascade $\gamma$-decay of compound state after the thermal neutron capture is not selective to within some tens percent. I. e., the known “scissors mode” states, quasi-particle, phonon or more complicated states are excited by cascades practically with equal probability.

According to the notions of the quasiparticle-phonon nuclear model [2], the probability of the neutron capture is determined by the single-particle components of the wave function of the neutron state. As it was estimated by V.G.Soloviev, their contribution into the total normalization of wave function of deformed nucleus equals $10^{-9}$. So, the authors of QPNM did not need to introduce some exotic hypotheses, like that used in [1], for description of such process as the emission the primary $\gamma$-transition.

1 New data on the parameters of the cascade $\gamma$-decay

Analysis [4] of a bulk of the information on the two-step cascades, made in FLNP without the model notions on level density $\rho$ and radiative strength functions $k$, showed that these data cannot be reproduced without the presence of step-like structure in level density and corresponding deviations of $k$ from the simple model dependences. For the first time, the possibility of the step-like structures in the level density and corresponding thermodynamical characteristics of a nucleus was pointed out in [5].

2 Analysis

Using our early [6] experimental data on cascade $\gamma$-transitions from the $^{162}$Dy$(n, \gamma)$ reaction we determined the dependence [7] of the two-step cascade intensity $I_{\gamma \gamma}(E_1)$ on the primary tran-
sition energy $E_1$, and also level density $\rho$ and radiative strength functions $k = \Gamma_{\lambda i}/(E_\gamma^3 A^{2/3} D_\lambda)$ which allow us to reproduce $I_{\gamma\gamma}(E_1)$ (shown in Fig. 1) with zero deviation from the experiment.

Although efficiency of the spectrometer used in the experiment [6] was not enough, rather specific form of energy dependence of the cascade intensity (considerable concentration of $I_{\gamma\gamma}$ at the energy of their intermediate levels $E_i \simeq 0.5 B_n$) decreases systematical uncertainties of the procedure [7] for the primary transitions of cascades with the energy $E_1 \leq 2$ MeV. The most considerable errors of procedure [7] – decomposition of the experimental spectrum into two components corresponding to solely primary transitions and to solely secondary transitions – leads to re-distribution of cascade intensities in $^{163}$Dy (Fig. 1) between the intervals of the primary transition energies 2-3 and 3-4 MeV. Modelling of influence of this uncertainty on the desired parameters of the cascade $\gamma$-decay process shows that this does not lead to principle change in the forms of the energy dependences of level density and radiative strength functions. For the energy of the primary transition $E_1 \leq 2$ MeV in Fig. 1, corresponding overage in cascade intensity does not exceed 0.1 of the given value. This conclusion follows from the extrapolation [8] of the cumulative sums of cascade intensities in some energy intervals of their intermediate levels to the zero detection threshold of individual cascades. This systematical error leads, in practice, to insignificant variation in values of the desired parameters.

Level density and radiative strength functions of $E1$ and $M1$ cascade transitions, which allow simultaneous reproduction of cascade intensity $I_{\gamma\gamma}(E_1)$ (Fig. 1) and the mean value of the total radiative width $\Gamma_\lambda = 150$ meV [9] of neutron resonances in $^{162}$Dy, are shown in Figs. 2 and 3, respectively. As in the other studied even-odd nuclei, level density in $^{163}$Dy also considerably less of [10] in the excitation interval from 1 to 3 MeV. Theoretical basis for qualitative explanation of such energy dependence was obtained in [5]. In accordance with the main idea of A.V. Ignatyuk and Yu.V. Sokolov, quasi-particle level density is the sum of densities of levels with 1, 3, 5... quasi-particles for even-odd nuclei. In the interval between the energies of breaking of corresponding Cooper pair, level density changes very weakly, at least for some first broken pairs. And energy of a nucleus, most probably, is passed for excitation of its vibrations. The only correction which is necessary to achieve well agreement between the experiment and calculation [5] is the shift to the higher value of the energy of appearance of 3 quasi-particles by about 1 MeV.

The increase in radiative strength functions in the interval $1.5 \approx E_1 \approx 4.5$ MeV results, most probably, from the change in the ratio between the quasi-particle and collective components of wave functions of the cascade intermediate levels in the region of the biggest deviation of their density from the predictions of the Fermi-gas model.

3 On ambiguity of different methods to analyse cascade intensities

Method [4] does not allow one, even in principle, to get unique values of the level density and radiative strength functions and in that case when experimental data do not contain systematical and statistical errors. Modelling of this situation shows that such their asymptotical uncertainty for the available experimental data cannot be less than $\approx 20\%$. This result is to:
(a) exceeding of the number of the determined parameters over the number of experimental points, and

(b) specific form of the functional dependence of $I_{\gamma\gamma}$ on the desired parameters $\rho$ and $k$.

The possibility to get reliable information on $\rho$ and $k$ strongly increases if some hypothesis is tested by means of comparison between the calculated within according to this hypothesis and experimental distributions of cascade intensities. In general case, some model ensemble of the $\rho$ and $k$ values allow one to calculate some value $M_{\gamma\gamma}(E_1)$ of cascade intensity and bilaterally symmetrical to it distribution $M_{\gamma\gamma}(E_2)$ intensity of cascades to their different final levels.

The case $M_{\gamma\gamma}(E_1) + M_{\gamma\gamma}(E_2) = I_{\gamma\gamma}(E_1) + I_{\gamma\gamma}(E_2)$ is the necessary condition for correspondence between the model and experimental values of $\rho$ and $k$ but it is not enough condition. It is obvious, because the condition $M_{\gamma\gamma}(E_1) = I_{\gamma\gamma}(E_1)$ does not follow from previous equation. This means that the experimental spectra can be reproduced with the help of much larger set of values of $\rho$ and $k$ that it is necessary for reproduction of the data in Fig. 1.

The authors of [1] and, for example, [11] do not take this important circumstance into consideration.

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Fig. 1 The total experimental intensities (in % per decay) of two-step cascades (summed in energy bins of 500 keV) with ordinary statistical errors as a function of the primary transition energy.
Fig. 2 The interval of probable values of the level density enabling the reproduction of the experimental cascade intensity and total radiative width of capture state. The line represents predictions of model [10].
Fig. 3 The probable interval of the sum strength function $k(E_1) + k(M1)$ (points with error bars) providing the reproduction of the experimental data. The upper and lower curves represent the extrapolation of the GEDR “tail” into the region below $B_n$ and the predictions of model [12], respectively.