

LEVEL DENSITY AND RADIATIVE STRENGTH FUNCTIONS OF DIPOLE γ -TRANSITIONS IN ^{139}Ba AND ^{165}Dy

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Abstract

Level density and radiative strength functions which allow precise reproduction of the two-step cascade intensity, gamma width of compound state and cascade population of levels up to excitation energy of about 3.5 MeV were determined using experimental data on the $(n, 2\gamma)$ reaction. Level density in these (like in other even-odd nuclei studied earlier) in wide excitation energy interval is considerably less than that predicted by Fermi-gas model. Enhancement of the radiative strength functions, caused by strong correlations between cascade gamma-decay parameters, most probably, relates with the change in ratio between the quasi-particle and collective components of the wave functions of the cascade intermediate levels in the region of most strong change in their density.

Introduction

The authors [1] have studied Cooper pairs breaking process by comparison of level density in threes of isotopes with the neutron number $N - 1$, N , $N + 1$. The confidence level in determination of nuclear specific heat is fully stipulated by reliability of the observed level density. This nuclear parameter obtained from intensities of two-step cascades has considerably higher reliability than that obtained within known methods due to unsuccessful relation between the experimental spectra and desired parameters of the gamma-decay process. The data needed for the analysis [1] can be obtained now, for example, for three compound nuclei $^{137,138,139}\text{Ba}$ and $^{163,164,165}\text{Dy}$.

Analysis method [2] of a bulk of the information on the two-step cascades, developed in Dubna without using any the model notions of level density ρ and radiative strength functions k , showed that these data cannot be reproduced without the "step-like" structure in level density and corresponding deviations of k from the simple model dependencies. For the first time, the possibility of the "step-like" structures in the level density and corresponding thermodynamic characteristics of a nucleus was pointed out in [3].

1 Analysis

Using our experimental data on cascade γ -transitions from the $^{139}\text{Ba}(n, 2\gamma)$ [4] and $^{164}\text{Dy}(n, 2\gamma)$ [5] reactions we determined [6] the dependence of the two-step cascade intensity $I_{\gamma\gamma}(E_1)$ on the primary transition energy E_1 for these nuclei (it is shown in Fig. 1), and also level density ρ and radiative strength functions $k = \Gamma_{\lambda i}/(E_{\lambda}^3 A^{2/3} D_{\lambda})$ which allow us to reproduce $I_{\gamma\gamma}(E_1)$ with practically zero deviation from the experiment for both nuclei. The most considerable errors of procedure [6] of decomposition of the experimental spectrum into two components corresponding to solely primary transitions and solely secondary transitions - leads only to re-distribution of cascade intensities between the different intervals of the primary transition energies.

In the first approach, magnitude of this error is inversely proportional to the number of cascades registered in the experiment. It increases also with increasing a number of background events.

Although efficiency of the spectrometer used in the experiment [4,5] was small enough, rather specific form of energy dependence of the cascade intensity (considerable concentration of $I_{\gamma\gamma}$ at the energy of their intermediate levels $E_i \simeq 0.5B_n$ for ^{165}Dy) decreases the influence of systematical uncertainties of the procedure [6] for the primary transitions of cascades with the energy $E_1 \leq 2$ MeV. In practice, this can increase cascade intensity for $E_1 \geq 2$ MeV not more than by 20-30% and, respectively, decrease it in the same measure in the region $E_1 \geq 3.7$ MeV.

In case of ^{165}Dy , the ρ and k data obtained from analysis [2] are slightly misrepresented. But the use of the method [6] does not change the total cascade intensity in the $2 < E_1 < 3.7$ MeV interval. Namely, considerable exceeding of experimental intensity at high enough nuclear excitation $E_{ex} = B_n - E_1$ above the calculation in the framework Fermi-gas [7] model of level density or any other notions (which provide exponential energy dependence of level density in the interval from 1-2 MeV and B_n) gives "step-like" structure in energy dependence of level density. As a consequence, this systematical error leads, in practice, to insignificant variation in values of the desired parameters ρ and k . Just this circumstance allow us to get the data on the level density and radiative strength functions with relatively small systematic errors.

Additional error can result from systematic errors of intensities of the cascade high-energy primary gamma-transitions which are used for normalization of $I_{\gamma\gamma}$. Intensities [5] used for this aim are about 25% less than the modern values [9]. So, one can summarize that all the known ordinary systematic errors cannot decrease the presented below experimental level density at least at the excitation energy $E_{ex} < 3$ MeV. Such systematical error can not explain the difference between experimental and calculated data in ^{139}Ba even in principle also.

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 $\Gamma_{\lambda} = 55$ and 57 meV [10] of neutron resonances in ^{138}Ba and ^{164}Dy correspondingly, are shown in Figs. 2 and 3, respectively.

It was established experimentally in first time now [12] that the ratio

$k(E_\gamma, E_{ex})/k(E_\gamma, B_n)$ of strength functions for transitions with equal energy and multipolarity but depopulating levels with significantly different excitation energy strongly depends on E_{ex} . This must lead to significant discrepancy between the calculated and experimental single spectra of cascade gamma-decay of any nuclei and to noticeably less discrepancy in the case of intensities of two-step cascades to the most low-lying levels.

This is due to the sign-variable variation of energy dependence of strength functions $k(E_\gamma, E_{ex})$ of the secondary transitions with respect to $k(E_\gamma, B_n)$ for the primary transitions. Such variations influence corresponding $I_{\gamma\gamma}$ values only through the considerably less change in the total radiative strength of the cascade intermediate levels. But even in this case, the errors in parameters can exceed the width of the interval of probable values ρ and k providing precise description of the experimental cascade intensities.

The use of cascade population of the large enough set of cascade intermediate levels with rather high maximum excitation energy provides, to the first approach, accounting [12] for the dependence $k(E_\gamma, E_{ex})$. Corresponding results for population by cascades and primary transitions of such set of levels are shown in Fig. 4, the lower estimates of cascade populations summed over the 200 keV energy bins are shown in Fig. 5. The last data can be added to the set of experimental data using for extraction [2] of ρ and k . This provides as low as possible error in determination of the parameters to be found.

As in other studied even-odd nuclei, level density in ^{139}Ba ^{165}Dy in the excitation interval from ~ 1 to ~ 3 MeV also is considerably less than that predicted according to [7]. Theoretical basis for qualitative explanation of such energy dependence was obtained in [3]. In accordance with the main idea by A.V. Ignatyuk and Yu.V. Sokolov, quasi-particle level density is the sum of level densities with 1, 3, 5... quasi-particles for even-odd nuclei. In the interval between the energies of breaking of corresponding Cooper pairs, level density changes very weakly, at least for some first broken pair. And energy of a nucleus, most probably, is passed to excitation of its vibrations. The only correction which is necessary to achieve well agreement between the experiment and calculation [3] is the shift of the energy of appearance of 3 quasi-particles to the higher value by about 1 MeV. Enhancement of the radiative strength functions, caused by strong correlations of k and ρ , most probably, relates with the change in ratio between the quasi-particle and collective components of the wave functions of the cascade intermediate levels in the region of most strong change in their density.

2 Conclusion

Method [2] does not allow one, even in principle, to get unique values of the level density and radiative strength functions even in that case when experimental cascade intensities do not contain systematical and statistical errors. Modeling of this situation shows that their asymptotical uncertainty for the available experimental data cannot be less than $\approx 20\%$. This results from:

(a) exceeding of 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 ρ and k .

But even in this case the determined parameters should be considered as the most reliable among the analogous results, first of all, due to model-free method of their determination.

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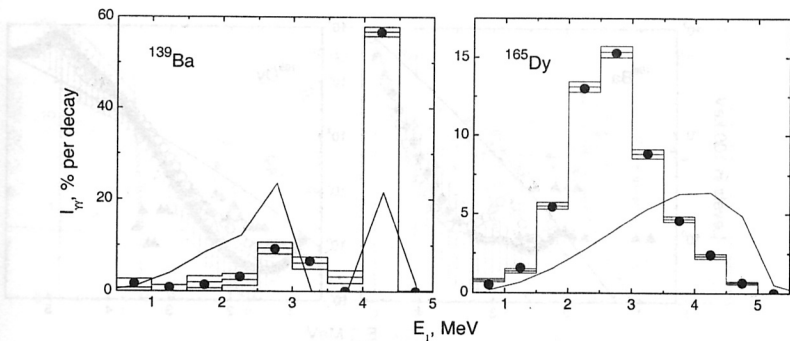


Fig. 1. Histogram is the total experimental intensities of two-step cascades (summed in energy bins of 500 keV) with ordinary statistical errors as a function of the primary transition energy. Line is the calculation in frame of models [7,9]. Points are the typical fit by the most probable values ρ and k .

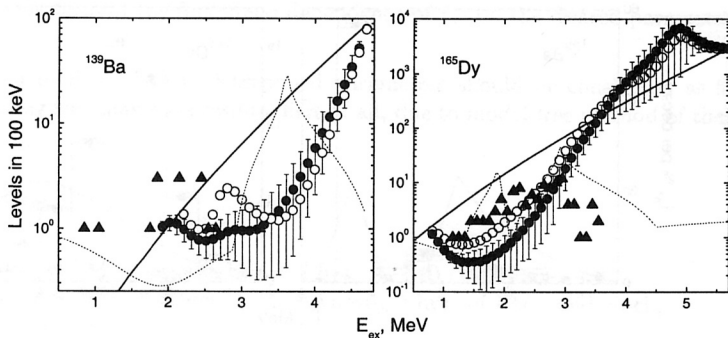


Fig. 2 Full circles are the expected number of levels for both parities and spins 1/2, 3/2 in case of different functional dependence of strength functions for primary and secondary cascade transitions. Open circles are the same for equal functional dependence of strength functions for primary and secondary cascade transitions. Dash lines shows values of function h [12] for excitation energy $E_{ex} = B_n - E_1$. Lines represents predictions according to model [7]. Triangles are the number of obtained in [4,5] two-step cascades intermediate levels.

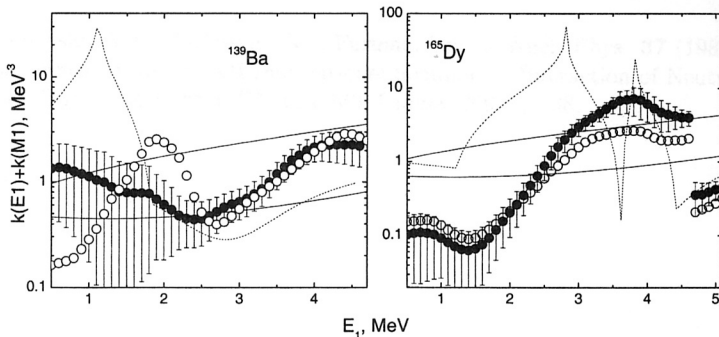


Fig. 3 The sums of radiative strength functions of the cascade primary dipole transitions providing reproduction of cascade intensities with the considered difference of their values with strength functions of secondary transitions (multiplied by 10^9). Open circles are the same for one equal energy dependence of strength functions for primary and secondary cascade transitions. Dash lines shows values of function h for excitation energy $B_n - E_1$. Lines are the models [9,11] predictions with $k(M1) = const.$

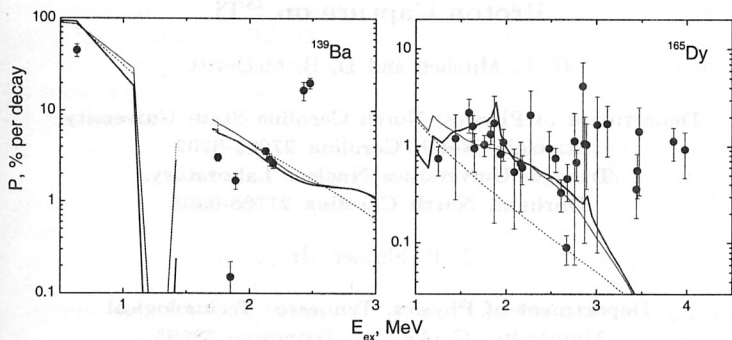


Fig. 4. The total population of intermediate levels of two-step cascades (points with bars), dashed line represents calculation within models [7,9]. Thin line shows results of calculation using data [2]. Thick line shows results of calculation using level density [2], and corresponding strength functions of secondary transitions are multiplied by function h determined within method [12].

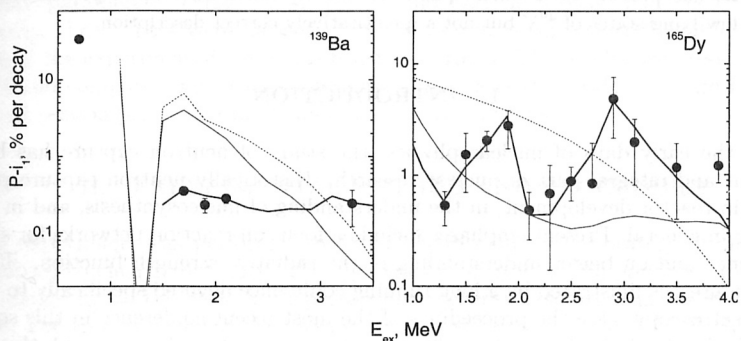


Fig. 5. The same as in Fig. 4 for sum of the cascade population only for levels in the 200 keV energy bins.