

**PARAMETERS OF CASCADE GAMMA-DECAY OF
COMPOUND-NUCLEI ^{146}Nd , ^{156}Gd , ^{172}Yb , ^{182}Ta , ^{184}W , ^{191}Os , $^{231,233}\text{Th}$, ^{239}U ,
 ^{240}Pu FROM EXPERIMENTAL DATA OF REACTION (\bar{n}, γ)**

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Abstract

Re-analysis of experimental data on primary gamma-transitions averaged over some energy intervals of neutron resonances has been performed. Approximation of their cumulative sums together with extrapolation of the obtained distribution to zero value allowed us to determine mean intensities of E1- and M1-transitions, their probable number and total dispersion of intensity deviations from the mean value. The level density and sum of radiative strength functions determined in this way confirm main peculiarities of these nuclear parameters determined from intensities of the two-step gamma-cascades.

1 Introduction

Level density ρ and radiative strength functions $k = \Gamma/(E_\gamma^3 D_\lambda A^{2/3})$ of the dipole primary transitions of the neutron resonance gamma-decay provided us with a considerable portion of experimental information on both nuclear properties on the whole and nuclear resonances – in particular.

Nevertheless, there is an urgent necessity in determination of these data in new independent experiments. The ground for this is principle incompatibility of experimental data on ρ and $k(E1) + k(M1)$ obtained in two-step reaction $(n, 2\gamma)$ [1, 2] with analogous data from one-step reactions like (p, n) [3, 4], $(d, p\gamma)$ [5] and $(^3\text{He}, \alpha\gamma)$ [6].

Partial analysis of possible reasons for this discrepancy was performed, for example, in [7]. It results in the following statements:

a) transfer coefficients of total errors in determination of partial cross-sections of two-step reactions onto errors of the parameters under determination are much less than those determined in one-step reactions like $(d, p\gamma)$, $(^3\text{He}, \alpha\gamma)$ due to other form of functional dependence between subjects “spectrum” and “parameters”;

b) the same concerns sensitivity of the determined parameters to degree of erroneous of hypothesis by Bohr-Mottelson [8] (Axel-Brink [9, 10]) for gamma-quanta) of independence of interaction cross-section of final reaction product in reverse reaction with the excited final nucleus.

In practice, error in absolute normalization of the two-step spectra by order of $\pm 25\%$ changes the ρ and $k(E1) + k(M1)$ values not more than by a factor of two [11] near $E_{ex} \approx 0.5B_n$. This is the largest systematical error in these experimental data. Analogous error of the total gamma-spectrum normalization for different excitation energies $0 \leq$

$\Delta S/S \leq 1\%$ in one-step (according to the used analysis method) reaction $(d, p\gamma)$ or $({}^3\text{He}, \alpha\gamma)$ brings [12] to more than 100% errors in intensities of all the spectra of only primary gamma-transitions, at least, for $E_\gamma \leq 0.5$ MeV. The coefficients of further transfer of the indicated error on the determined values of the parameters, until now, were not determined by anyone. It is possible to suggest in this situation, that ρ and $k(E1)+k(M1)$ determined according to [6] have arbitrary systematical errors for different excitation and primary gamma-transitions energies.

Direct experimental verification of hypotheses [8, 9, 10] is impossible. But, the possibility of obtaining functionals directly depending on unknown partial cross-sections of reaction for excited target-nucleus was found in [2]. Cascade population of levels determined there for the majority of ≈ 20 nuclei up to excitation energy of $E_{ex} \sim 3 - 5$ MeV cannot be reproduced in frameworks of Axel-Brink hypothesis. However, they can be easily enough reproduced under assumption of existing enhancement of primary and secondary gamma-transitions to the region of “step-like” structure in level density [1, 2].

Unfortunately, complete notion of the observed by this method function $k(E1) + k(M1) = f(E_\gamma, E_{ex})$ cannot be obtained due to lack of experimental data. But, as it is seen from comparison between the results [13, 14] and the data [1, 2], violation of hypothesis [9, 10] is considerably larger than it was obtained in [2]. For this reason, level density obtained in [1, 2] can be overestimated by several times in excitation region $\sim 0.5B_n$. Most probably, this error gradually decreases at lower and higher excitation energy of nucleus under condition that the experimental data on density of low-lying levels and neutron resonances have significantly lesser errors. Strength functions $k(E1) + k(M1)$ are, most probably, underestimated.

Due to this reason, authors [1, 2] performed independent model-free re-analysis of the experimental data from the (\bar{n}, γ) reaction in frameworks of only mathematical statistics with the least number of assumptions on parameters of small sets of the primary gamma-transition partial widths. It was obtained that the refusal from main postulates of “statistical” theory brings to conclusion which confirms main results of [1, 2].

2 Main principles of analysis

Capture of neutrons in “filtered” beams, for example, noticeably enough averages the gamma-transition partial widths in local resonances. This is true for nuclei with small enough spacing D_λ between neutron resonances. It is possible to observe experimentally the width Γ with relative statistical error σ if its value exceeds practically constant detection threshold L of experiment (in any given narrow interval of gamma-transition energy).

The portion of primary gamma-transitions of the same multipolarity and practically equal energy with $\Gamma < L$ is determined by concrete form of deviation distribution of Γ from mean value in individual resonances and their effective number for neutron beam in experiment.

It follows from main statements of modern nuclear theory that the amplitude of gamma-transition between neutron resonance and low-lying level is determined by quasi-particle and phonon components in wave functions of both levels (see, for instance, [16]). Their concrete values are determined by fragmentation degree of the states like n quasi-particles and m phonons over nuclear levels at different excitation energy. In accordance with [17], this process is rather specific – strength of the fragmented state is distributed very irregularly. In many cases, its strength is fragmented over the levels lying near the initial position of non fragmented state.

In practice, this means that the Γ values must strongly and locally depend on structures of decaying and excited levels. Their dispersion relative to the average must be determined by number and value of the wave function components of these levels. Therefore, fluctuations of $\Gamma / \langle \Gamma \rangle$ cannot be described by universal distribution. Its deviation from the generally adopted Porter-Thomas distribution [18] must be determined in every case experimentally. Practically, it is adopted in analysis (see [13]) that the sum of dispersions of experimental statistics uncertainty and “nuclear fluctuations” is equal to $\sigma^2 = 2/\nu$ with unknown parameter ν .

The second assumption of analysis is that the gamma-transitions of the same multipolarity with energy of about some hundreds keV have the same mean value. In principle, this assumption can be mistaken and, for instance, mean widths of all the gamma-transitions involved in the set under analysis can belong to some rather wide interval of possible values. Moreover, the probability of given mean value may increase as decreasing $\langle \Gamma \rangle$.

This possibility is to be investigated experimentally. Real width distribution around the average determines reliability of both data presented below and conclusions of [1, 2].

3 The most reliable values

The values of level density and radiative strength functions of primary gamma-transitions obtained by analogy with [13] are presented in figs. 1–4. The distribution of cumulative sums of reduced intensities for the analyzed nuclei [19] - [28] and parameters of approximating curve have no principle difference with that given in [13, 14, 15]. Therefore, they are not presented in this work.

The gamma-decay parameters of nuclei determined in [1, 2] are compared with results of two different in principle methods of analysis. Accounting for results of theoretical analysis [17] (possible dependence of the wave function components of levels determining Γ on energy of neutron resonances) one can conclude that the discrepancy between results of two methods of analysis mentioned above is less than their difference from the data [4, 6].

It follows, first of all, from observation of “step-like” structure in level density in both methods [1, 2, 13] and close to zero or negative derivative $d(k(E1) + k(M1))/dE_1$ for the same excitation region of nucleus. *Id est*, the local peak in sum of strength functions must be more or less clearly expressed.

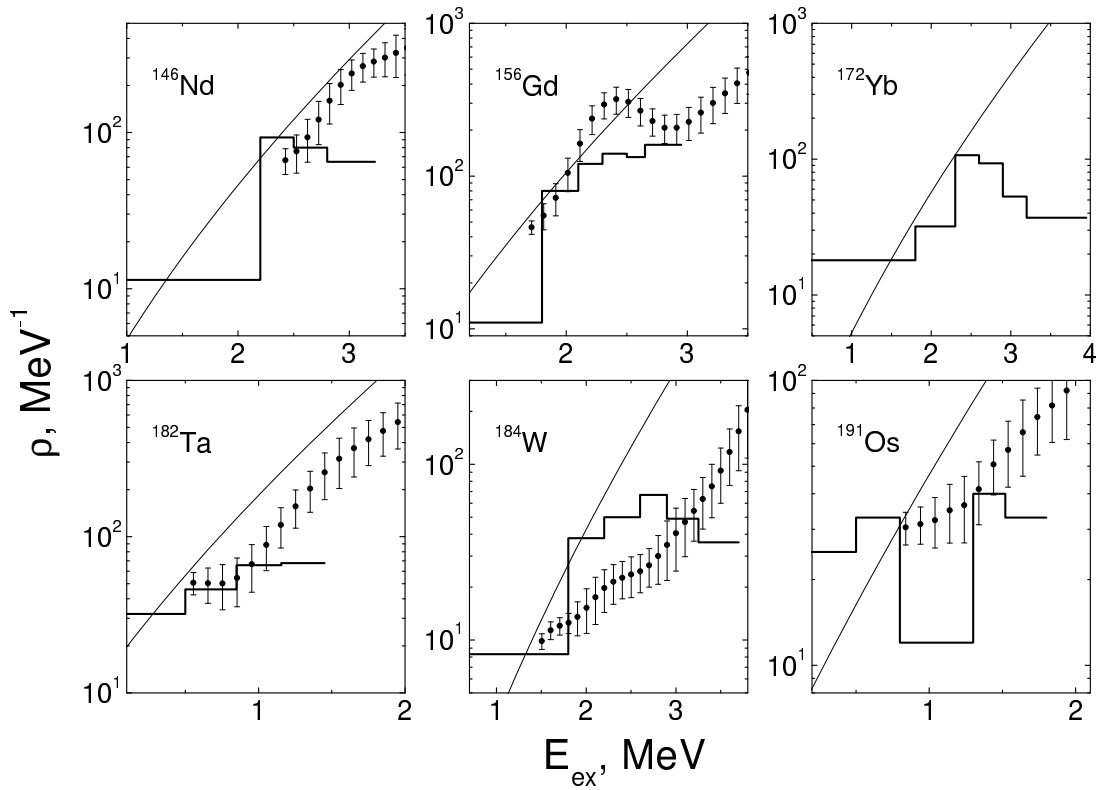


Fig. 1. Comparison of different data on level density for the ^{146}Nd , ^{156}Gd , ^{172}Yb , ^{182}Ta , ^{184}W and ^{191}Os nuclei. Curve represents the calculated within model [29] density of levels populated by the primary gamma-transitions. Results of presented analysis – histogram, points with errors – data [1] and [2].

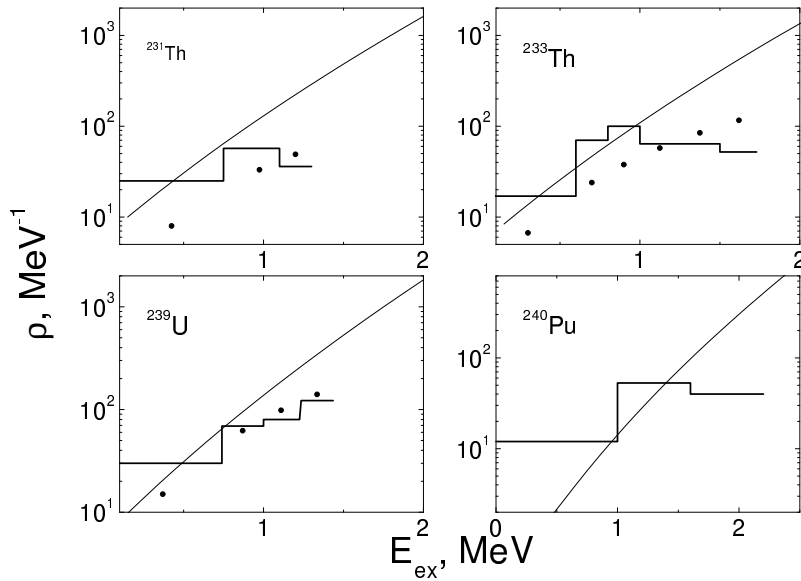


Fig. 2. The same, as in Fig. 1, for $^{231,233}\text{Th}$, ^{239}U and ^{240}Pu . Points show approximation of the experimental data by density of two- or three-quasiparticle levels of model [31] with the independent on excitation energy coefficient of collective enhancement.

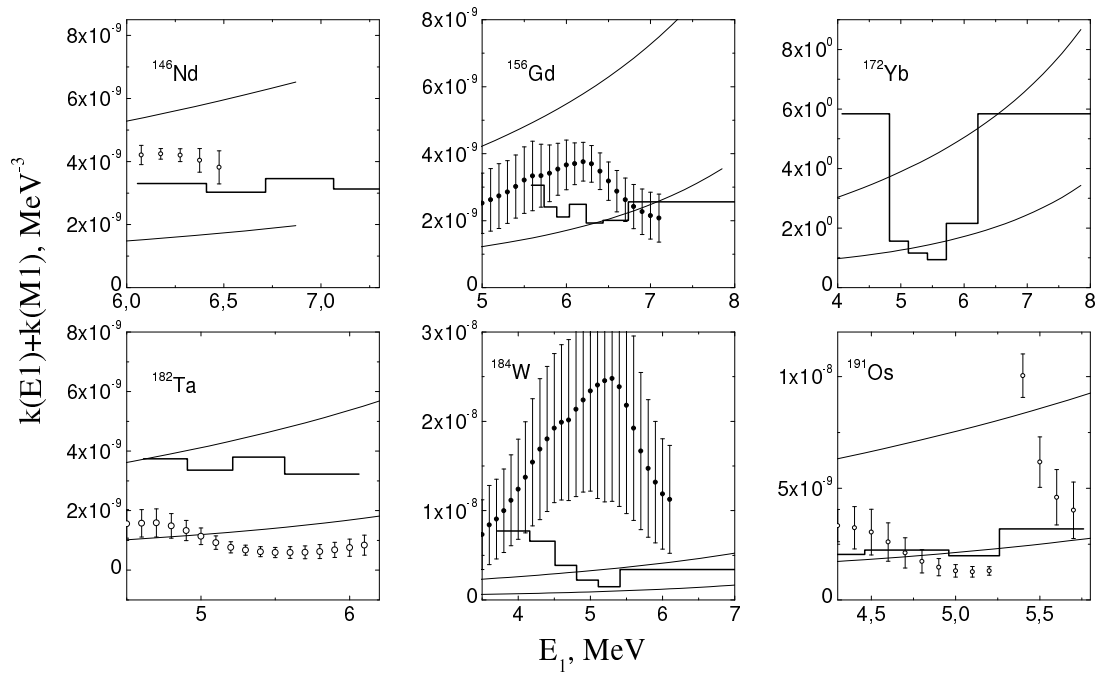


Fig. 3. The same, as in Fig. 1, for sums of the radiative strength functions. Results of analysis performed in this work are presented as histogram of relative values. Upper curve - [9], lower curve - [30] together with $k(M1)=\text{const}$. Points with errors show the data [1, 2].

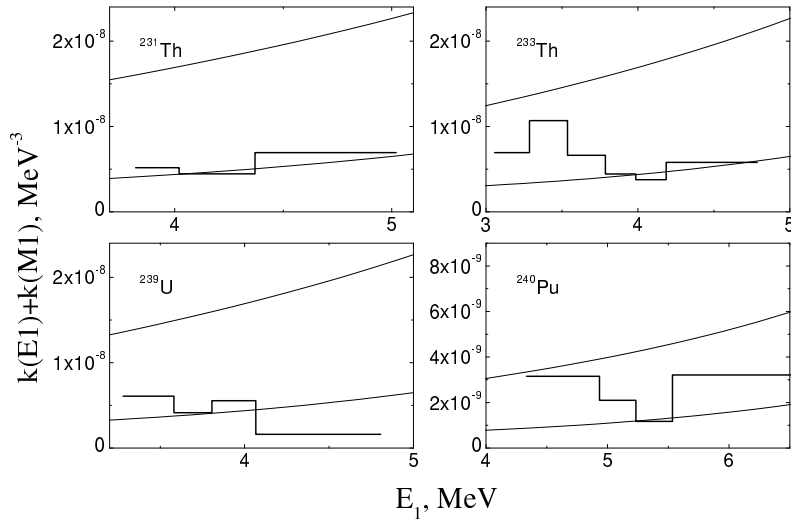


Fig. 4. The same, as in Fig. 3, for ^{231}Th , ^{233}Th , ^{239}U and ^{240}Pu .

The data presented in figs. 1, 2 confirm also conclusion on probable local increase in density of vibration type levels in the region of the nucleon pairing energy for a nucleus of a given mass. The shape of this dependence is presented in details in [13, 14, 15].

4 Conclusion

Unfortunately, energy interval of the primary gamma-transitions observed in experiment is considerably less than that for $^{157,159}\text{Gd}$, ^{174}Yb and ^{237}U . Nevertheless, the data shown in figs. 1-4 bring to the following conclusion: notions of a nucleus as a system of non-interacting Fermi-gas and ideas of other analogous nuclear models [32] are insufficient for reproduction of modern experimental data.

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