LEVEL DENSITY AND RADIATIVE STRENGTH FUNCTIONS OF THE ^{237}U NUCLEUS FROM THE $(\overline{n}, \gamma)$ REACTION

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Abstract

The independent analysis of the published data on the intensities of the primary γ-quanta following resonance neutron capture in ^{236}U has been performed. Distribution of these intensities about the mean value was approximated in different energy intervals of the primary gamma-transitions and neutrons. Extrapolation of the obtained functions to the zero registration threshold of the primary gamma-transition intensity allowed us to estimate (independently on the other experimental methods) expected level number of both parities for spin values J=1/2, 3/2 and sum of radiative widths for both electric and magnetic dipole gamma-transitions to levels with excitation energy up to ≈ 2.3 MeV. Level densities and sums of radiative strength functions determined in this way confirm characteristic behavior of analogous data derived from intensities of the two-step cascades following thermal neutron radiactive capture in nuclei from the mass-region $40 \leq A \leq 200$. Besides, this permits one to estimate sign and magnitude of systematic uncertainties for their model predicted values, at least, below one half of the neutron binding energy. Comparison with the model notions of level density testifies to super-liquid phase of this nucleus for the main part of excited levels, at least, below 2.3 MeV.

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1 Introduction

Precise models of level density ρ and radiative strength functions $k = \Gamma/(E_\gamma^3 D_\lambda A^{2/3})$ of the populated them primary dipole gamma-transitions at the neutron radiative capture are necessary for estimation of experimental neutron cross-sections and their calculation at lack of experimental data. First of all, it is necessary for actinides.

Available [1] models, most probably, do not satisfy modern requirements to these data [2]. Their insufficient quality is conditioned by clearly small volume of reliable experimental data on level density and emission probability, for example, of gamma-quanta. This results from significant errors of experiments performed up to now. Underestimation of uncertainties is largely caused by the use of obsolete notions of a nucleus for analysis of experiment.

An increase of reliability level of the experimental data on ρ and k demands one to develop new methods for their determination at obliged minimization of number of any assumptions and hypotheses of mechanism of used nuclear reaction.

This condition is in high extent satisfied in analysis of the two-step gamma-cascade intensities following thermal neutron capture [3]. By means of this analysis it was observed for the first time the clearly expressed step-wise structure with a width of ~ 2 MeV in the level density ρ below $\approx 0.5B_n$ in a large set of nuclei. Further development of this method [4] brought to an additional determination of unknown fact of strong dependence of partial widths Γ_{if} of not only primary but also following gamma-transitions on the energy of the excited levels f in the region of the structure mentioned above.

Intensities $I_{\gamma\gamma}$ were measured up to now only for the case of thermal neutron capture. Accumulated experimental data allowed one to determine the ρ and k values for 42 nuclei [3] (in the framework of standard hypothesis [5, 6] on independence of radiative strength functions on nuclear excitation energy). For two tens of them these data were obtained at relatively realistic accounting for function $k(E_\gamma, E_{ex})$, experimentally estimated below excitation energy $E_{ex} \sim 3-5$ MeV [4].

It should be noted that the observed in [4] considerable dtviation of relation $R = k(E_\gamma, E_{ex})/k(E_\gamma, E_{ex} = B_n) = 1$ indirectly and relatively weekly influences the determined parameters of the cascade gamma-decay. This conclusion is true for the analysis of the intensities of the two-step gamma-cascades to the final levels with excitation energy $E_{ex} < 1$ MeV. In this case, the maximum change in the calculated total radiative width of cascade intermediate level (with accounting for function $k(E_\gamma, E_{\rm ex})$ derived from experiment) brings to decrease in the obtained according to [4] value of ρ in region of step-wise structure by a factor not more than 2 as compared with [3]. Therefore, method [4] provides the ρ and k values with the least at present systematic errors [7].

Nevertheless, obviously observed dependence of cascade intensity on the structure of all three levels included initial compound-state [8] stipulates for necessity to get new experimental data on ρ and k from the other experiments devoted to investigation of gamma-decay. In addition, the methods [3, 4] belong to class of reverse problems (determination of unknown parameters of functions measured in experiment) and, that is why, they require maximum possible verification and revealing all sources of systematic errors. In practice, this condition stipulates for necessity to get additional set of data on ρ and k from the maximum number of independent experiments. It is necessary also to solve the problem of estimating possible dependence of found according to [3, 4] gamma-decay parameters of high-lying levels on energy of neutron resonances λ and probable influence of their structures on the process under study. On the whole, analysis of the tendencies in determining ρ and k from solution of reverse tasks points to necessity in further investigations aimed to:

- estimation of adequacy of model notions of gamma-decay process to experiment and
- direct accounting for the coexistence and strong interaction between Fermi- and Bose-systems in the radiative strength function models. This must be done also in more details and more precisely in the level density models for nuclei of any mass and type.

2 Experimental data from the $(\overline{n},\gamma)$ reaction and method of their analysis

Both solution of the problem of correctness of model notions and necessity to study influence of the structure of the initial compound-states on the cascade gamma-decay process is up to now the primary aim of experiment. At present, this can be done in analysis of experimental intensities of the primary gamma-transitions following capture of “filtered” neutrons with energy 2 and 24 keV (or by any averaging over resolved resonances).

The most complete set of these data among actinides is accumulated for compound nucleus ^{237}U. Unfortunately, authors of corresponding experiments [9] used their data practically only for determination of spin and parity of excited levels on the base of notions of the limited “statistics” theory of gamma-decay. I.e., in the framework of the hypotheses:

- on independence of $k(E1)$ and $k(M1)$ on structure of decaying (λ) and excited (f) nuclear levels and
- applicability of the Porter-Thomas distribution [10] for describing random deviations of the gamma-transition partial widths in any interval of their energy from mean values.

There are no experimental evidences of hypothesis [5, 6, 10] for the data like [9] (concrete nucleus, given set of gamma-transition intensities). Therefore, the method of analysis must take into account possibility of non-execution of assumptions mentioned above.

2.1 Algorithm of analysis

The analysis is based on the following statements:

- the number of the primary dipole transitions observed in the $(\overline{n},\gamma)$ reaction is less than or equal to the value $\rho \times \Delta E$ for any excitation energy interval ΔE and spin window determined by the selection rule on multipolarity;
- the sum of widths of the observed transitions is less than or equal to the summed width of all the possible primary gamma-transitions;
- the likelihood function of approximation of distribution of random intensity deviations from the mean value has the only maximum;
- the experimental values of $\rho\Delta E$ and sum $\Gamma_{\lambda,f}$ can be determined with acceptable uncertainty from extrapolation by curve which approximates distribution of the random gamma-transition intensities to zero threshold of their registration;

- the averaging of random fluctuations of the primary gamma-transition widths over the initial compound states decreases dispersion of their distribution independently on reliability of hypothesis [10]. I. e., any set of gamma-transition intensities from the $(\overline{n},\gamma)$ reaction can be approximately described by the χ^2-distribution with unknown number of degrees of freedom ν. (In practice this distribution is close to normal one with dispersion $\sigma^2 \approx 2/\nu$.)

This means that the number of the primary gamma-transitions from reaction $(\overline{n},\gamma)$ with intensity lying below detection threshold of experiment [9] in any case considerably decreases as compared with analogous data obtained for decay of the only compound-state. In this case, determination of the primary gamma-transition intensity distribution parameters provides maximum possible precision for extrapolation of function of intensities random values distribution into the region below the detection threshold.

Therefore, precision in estimating the number of unobserved gamma-transitions and sum of their partial widths from the data [9] must be much higher than it can be reached by analysis of intensities of primary gamma-transitions following thermal neutron capture. Corresponding technique was developed earlier and tested on large set of the data on the two-step cascade intensities in [11].

The problem of principle importance in the analysis of such kind is really unknown law of distribution of dispersion of random widths about mean value. The fact of discrepancy between dispersion of random intensities of primary gamma-transitions and expected for a given nucleus value of ν at the capture of 2 keV neutrons was first pointed out in [12]. But up to now attempts to solve this problem were undertaken up to now.

The Porter-Thomas distribution correctly describes distribution of the random partial widths of the tested gamma-transitions only when their amplitudes have normal distribution with zero mean value. Therefore, they must be the sum of large number of items of different signs and the same order of magnitude. This condition must be fulfilled if wave-functions of the levels connected by gamma-transition contain a large amount of items with different signs and comparable magnitudes. Just these components are contained in matrix element for amplitude of gamma-transition.

2.2 Some aspects of modern theoretic ideas of gamma-transition probability

On the whole, existing theoretic developments, for example, quasiparticle-phonon nuclear model (QPNM) [13, 14] call some doubts about applicability of mentioned above primitive ideas of gamma-decay. In particular, the regularities of fragmentation of the different complicated states studied in the frameworks of QPNM [15] directly point to presence of items with considerable component of wave functions in the primary transition amplitudes. First of all, this concerns wave functions of excited levels [16], but it is not excluded that the wave-functions of decaying compound states (neutron resonances) also have large components [13]. This directly results in potential possibility of rather considerable violation of the Porter-Thomas distribution. These violations can appear themselves in limited [15] energy intervals of final levels and change dispersion of real distribution as compared with [10]. Correlation between absolute values of items in amplitude of any gamma-transition and their signs for the data like [9] are unknown. Therefore, the suggested below analysis of available experimental data must take into account possibility of strong dependence of the primary transition partial widths on structure and, correspondingly, energy of excited levels and cover all spectrum of their random deviations from the mean value. At least, it must guaranty obtaining the minimum possible estimation for ρ and the maximum possible – for k. Just this sign of deviation of their experimental values from the practically used [1] model ideas is provided by the analysis [3, 4].

According to theoretical notions of QPNM, the amplitude of gamma-transition from high-excited nuclear state (neutron resonance) is a sum of different in structure elements [13]. Schematically [17] they consist from a number of items which correspond to the following components of wave-functions of decaying and excited levels connected by the gamma-transition:

(a) n-quasiparticle,

(b) n-quasiparticle $\otimes$ phonon,

(c) n-quasiparticle $\otimes$ two phonons and so on.

I. e., amplitude of given gamma-transition can be determined by some components of physically different types. In common case they can have considerably different scale. And concrete values are determined by degree of fragmentation of the nuclear states enumerated above. The types of dominant components in the wave-functions of final levels excited by primary gamma-transitions can be different in principle, especially at low excitation energy of levels [16].

The first part of amplitude (see, for example, [17]) for many rather high-lying levels is determined by a number of items of different sign and, on the average, comparable magnitude. This qualitative explanation follows from calculation of structures of low-lying levels of deformed nuclei performed by authors [16] and the most general principles of fragmentation of nuclear states of complicated structure as increasing excitation energy [15].

The following items in the gamma-transition amplitude (at sufficient energy of excited level) account for contribution of those components which cause change in wave functions by one phonon. I.e., it follows from main theses of QPNM, for example, that the all multitude of the primary gamma-transition amplitudes cannot be reduced to one limited case as it was suggested in [10].

2.3 Some peculiarities of experimental data

Experimental investigations of various target-nuclei were performed in BNL. But only even-odd target-nucleus ^{236}U was chosen for the analysis presented below. This choice is stipulated by maximum interval of the primary gamma-transition energies listed in [9].

Even-odd compound-nucleus has an only possible spin at capture of s-neutrons and two possible – for p-neutrons. Analysis of intensities in the last case requires one to introduce and then determine the number of parameters corresponding to even-even nucleus. Even-odd compound nucleus at its excitation by s-neutrons represents methodically a particular case of the task considered in [18].

The width FWHM=850 eV of filtered neutron beam with the energy of 2 keV in the performed experiments was determined by interference minimum in the total cross section of scandium. The average spacing between neuron resonances in ^{236}U equals 12 eV and this provides minimum number of the primary gamma-transitions whose intensities are less than detection threshold.

If one does not account for:

(a) the change in neutron flux in the energy interval mentioned above;

(b) the possible strong correlation of partial radiative widths and

(c) the presence of noticeable statistic errors in experimental data

then dispersion $\sigma^2 = 2/\nu$ of their expected distribution can be not less than ~ 0.03. In presence of absolute correlation between reduced neutron width and partial radiative widths one can estimate maximum possible dispersion from the folding of two χ^2 dispersions by the value $\sigma^2 = 8/\nu \geq 0.12$.

I.e, the main part of the primary gamma-transition intensities observed in the nucleus under consideration must exceed experimental detection threshold. Therefore, expected errors of extrapolation must be small enough.

It is assumed in analysis that all the distributions of the primary gamma-transition intensities from reaction $(\overline{n}, \gamma)$ have only the following unknown parameters:

(a) the averaged reduced intensity $\langle I_\gamma^{max}/E_\gamma^3 \rangle$ of gamma-transitions populating levels $J = 1/2, 3/2$;

(b) the portion $B = \langle I_\gamma^{min} \rangle / \langle I_\gamma^{max} \rangle$ of reduced intensities of gamma-transitions to levels $J = 5/2$ relatively to that to levels $J = 1/2, 3/2$ (practically - for intensities of primary transitions following capture of neutrons with energy of 24 keV;

(c) the ratio $R_k = k(M1)/k(E1)$ which is independent on spin values of the levels populated by the primary transitions;

(d) the expected and equal numbers N_γ of gamma-transitions to levels $J = 1/2, 3/2$ and $J = 5/2$;

(e) as well as the dispersion σ^2 measured in units of degree of freedom ν.

Naturally, these parameters are to be determined independently for each energy interval of the primary gamma-transitions.

The presence of statistical errors in determination of each experimental value of $\langle I_\gamma/E_\gamma^3 \rangle$ automatically increases experimental dispersion σ^2 of distribution and decreases the ν value. It is assumed that their relative systematic errors in each energy interval are practically equal.

Of course, this notion assumes that the structures of initial compound-state and a group of levels in rather narrow interval ΔE of excitation energy connected by the primary gamma-transitions of the same type weekly influence the mean reduced intensities $\langle I_\gamma/E_\gamma^3\rangle$ of these quanta.

Both performed in [8] approximation and interpretation of experimental data on $k(E1)+k(M1)$ and ideas of modern nuclear theories show that this assumption can contain considerable uncertainty (especially for wide energy intervals of the primary gamma-transitions under study). But the maximum accuracy in determination of the most probable values of N_γ, B, R_k, ν and $\langle I_\gamma^{max}\rangle$ can be achieved, in principle, by recurrent optimization of the primary gamma-transition energy intervals where are determined these parameters.

One more problem is due to small volume of the set and difference in numbers of electric and magnetic dipole gamma-transitions in concrete intervals ΔE. Therefore, it is necessary to introduce and fix in analysis some assumption about number of levels of positive and negative parity in a given energy interval of nuclear levels. Below is used the hypothesis of equality of number of electric and magnetic gamma-transitions. In practice, this ratio can be varied for any possible hypotheses of ratio between level densities with different parity for any given excitation energy interval. The problem of difference in level density of different parity disappears for values of $R_k \approx 1$, the maximum error in determination of N_γ in case $R_k \approx 0$ corresponds to the lowest intensity transitions and insignificantly distorts desired sum $\sum\langle I_\gamma/E_\gamma^3\rangle$. In intermediate case, error of approximation will be stipulated, first of all, by difference in level densities of positive and negative parity – it will decrease as increasing excitation energy (as it was on the whole predicted by modern theoretical calculation of this nucleus parameter [19]).

Approximation of the mixture of the different type random values with respect to mean parameters by any distribution cannot determine their belonging to certain type without using additional information. But, accounting for the known fact that the magnetic gamma-transitions to the lowest levels are by order of magnitude weaker than electric transitions, one can extrapolate inequality $R_k = k(M1)/k(E1) < 1$ for the nuclei under study up to excitation energy where $R_k = 1$. There is not excluded that at higher energies of gamma-quanta $k(M1)/k(E1) > 1$.

Strength function of p-neurons $S_1 = 2.3(6)$ in isotope ^{236}U noticeably exceeds strength function of s-neutrons $S_0 = 1.0(1)$ [20]. Authors of [21] estimated that in this case the portion of captures of p-neutrons with energy of 2 keV equals approximately 15%. If one does not account for possible irradiation of small group of the primary dipole gamma-transitions following capture of p-neutrons and terminating at the levels with spin values $J = 5/2$, then the presence of this capture appears itself, most probably, as change in the R_k values for different energies of excited levels and corresponding increase of ν. Therefore, the presence of small number of the 2 keV p-neutron captures must not noticeably influence accuracy in determination of the expected values of N_γ and sum $k(E1)+k(M1)$.

There is no problem of p-neutron capture for the data on the intensities of primary gamma-transitions for resolved resonances. Absolute normalization of partial widths for each resonance performed in [9] allows one to provide for the most effective averaging of them. Unfortunately, arithmetic mean value of Γ_{if} inevitably shifts to lower values by different for each gamma-transition quantity $M \times \Delta\Gamma_{if}$. Partial width $\Delta\Gamma_{if}$ of each from M gamma-transition with intensity lying below registration threshold in given resonance varies from zero to some maximum magnitude. That is why, averaging over resonances additionally has this unknown specific error.

Approximation of distribution of random values I_γ/E_γ^3 was performed by analogy with [11] for cumulative sums in function of increasing values of intensities.

3 Results of analysis

The examples of experimental distributions of cumulative sums of the primary transition reduced intensities $\sum I_\gamma/E_\gamma^3 = F(\langle I_\gamma/E_\gamma^3\rangle, N_\gamma, \nu, R_k)$ were calculated for different values of concrete parameters and given in [18].

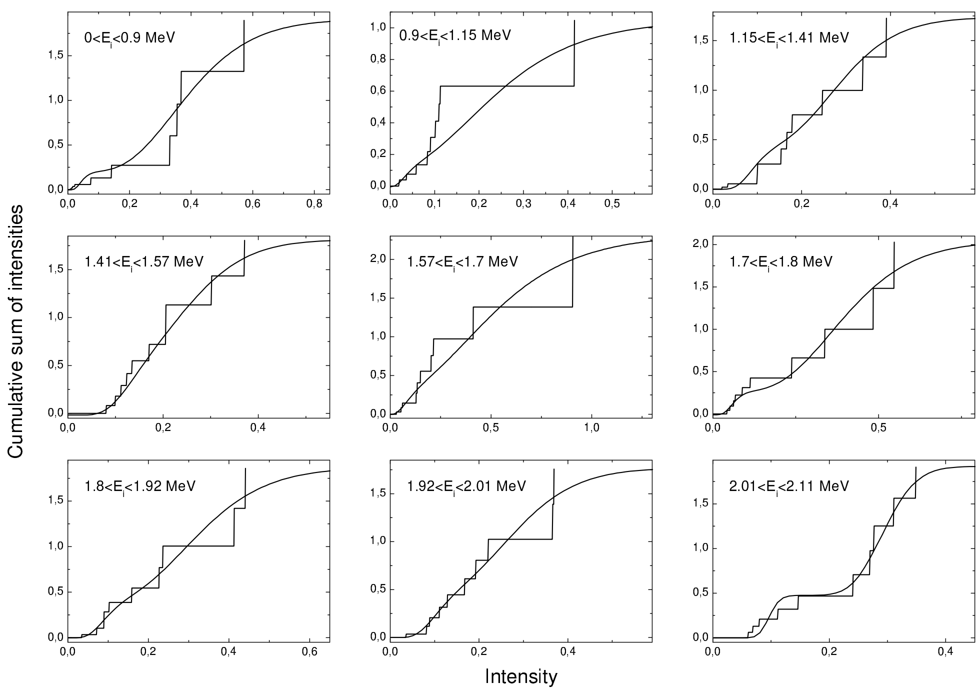

Fig. 1. The histogram represents experimental cumulative sum of reduced relative intensities $\langle I_\gamma\rangle/E_\gamma^3$ for ^{237}U. Smooth curve shows the best approximation. The intervals of excitation energy E_i of final nuclear levels are shown in figures. Experimental data for neutron energy $5 \leq B_n \leq 125$ eV.

This was done only under condition of correspondence between experiment and accepted hypotheses of the distribution form of the primary transition random intensities. The presence of functional dependence of the primary transition intensities on some "hidden" parameter can result in maximal errors of approximated values of the most probable number of gamma-transitions and dispersion of their deviation from mean value. Mod-

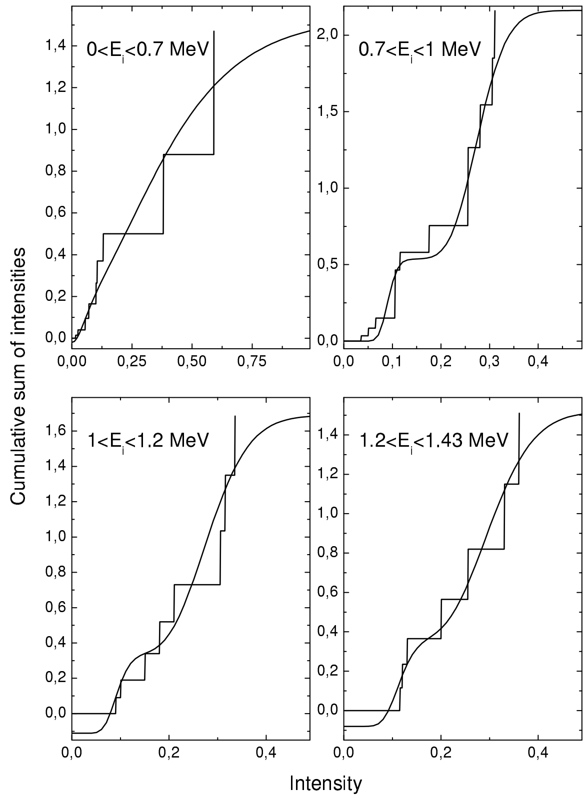

Fig. 2. The same, as in Fig. 1, for $E_n \approx 2$ keV.

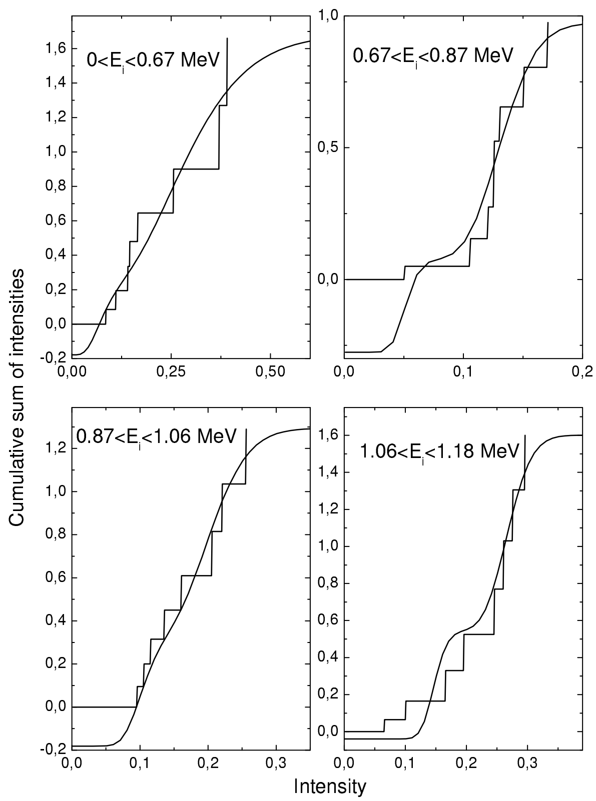

Fig. 3 The same, as in Fig. 1, for $E_n \approx 24$ keV.

ern nuclear theory does not consider this possibility; there are no experimental data on existence of "hidden" dependence, as well. Therefore, it is not taken into account below.

Experimental cumulative sums of the $\langle I_\gamma/E_\gamma^3\rangle$ relative values are shown in figs. 1-3 together with their best approximation. The data are presented so that the expected total intensity of gamma-transitions lying below detection threshold corresponds to the most probable value of cumulative sum for $\langle I_\gamma/E_\gamma^3\rangle = 0$.

At low energy E_i of final levels, accuracy in determination pf parameters of approximating curve must get worse due to inequality of level density with different parity. Most probably, this increases error of extrapolation of gamma-transition intensities to zero value. This can result in overestimating of N_γ values.

The best values of fitting parameters ν and R_k are are given in figs. 4 and 5. Noticeable change in these parameters of approximation for $0.7 < E_i < 1.2$ MeV points to considerable change in structure of given even-odd isotope in this excitation energy region.

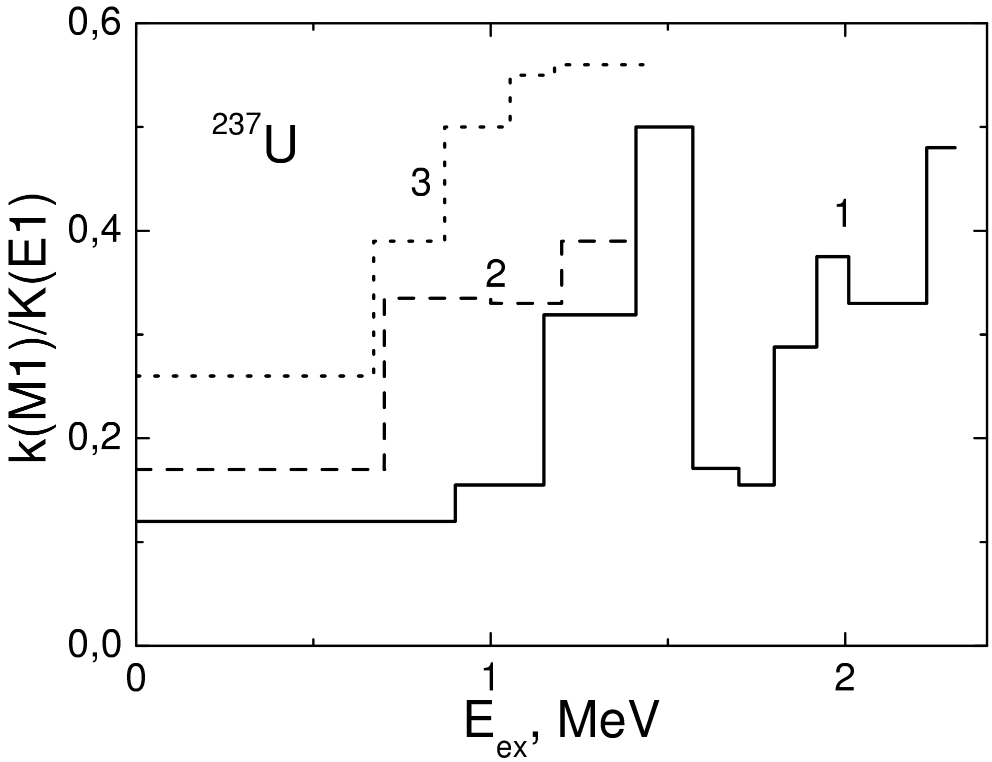

Fig. 4. The histograms represent the best values of ratio $k(M1)/k(E1)$ for different excitation energies of levels populated by dipole gamma-transitions. Line 1 represents data for $5 < E_n < 125$ eV, line 2 - for $E_n \approx 2$ keV and line 3 – for $E_n \approx 24$ keV.

The best values of level density $\rho = \sum_{J,\pi} N_\gamma/\Delta E$ and summed radiative strength functions $\sum\langle I_\gamma\rangle/(E_\gamma^3 N_\gamma)$ are given in figs. 6 and 7. Normalization of intensities and strength functions in both [3] and [9] was done to their absolute values. Because gamma-transition intensities following capture of "filtered" neutrons are listed in [10] in relative units than corresponding strength functions Fig.7 are combined with "resonance" values under assumption of their approximate equality.

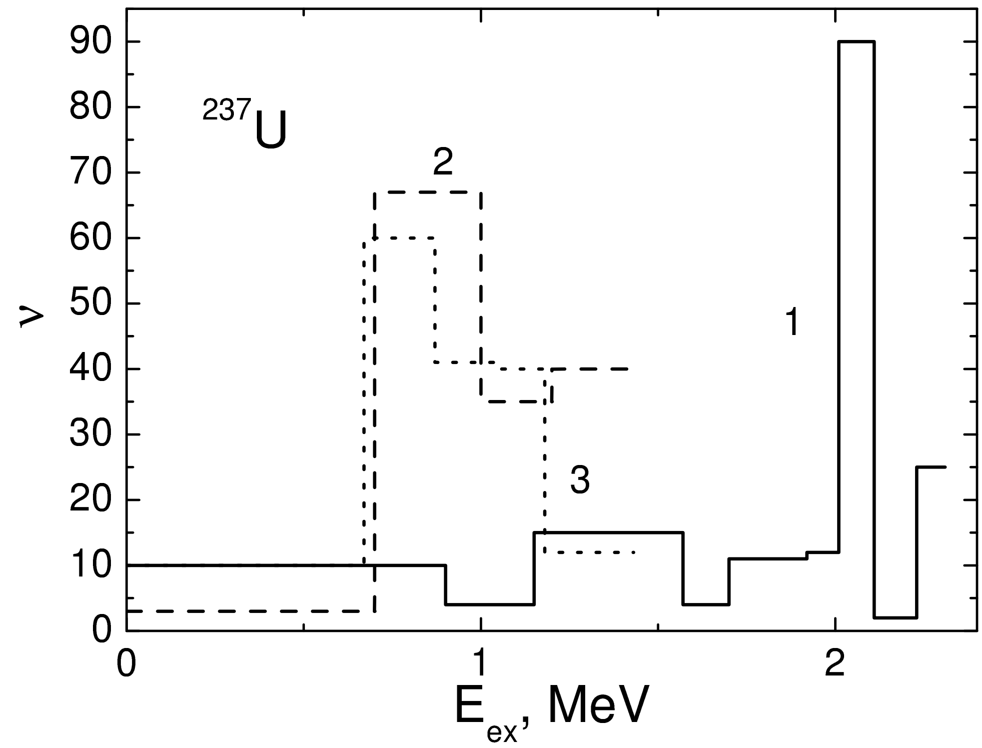

Fig. 5. The same, as in Fig.4, for parameter ν.

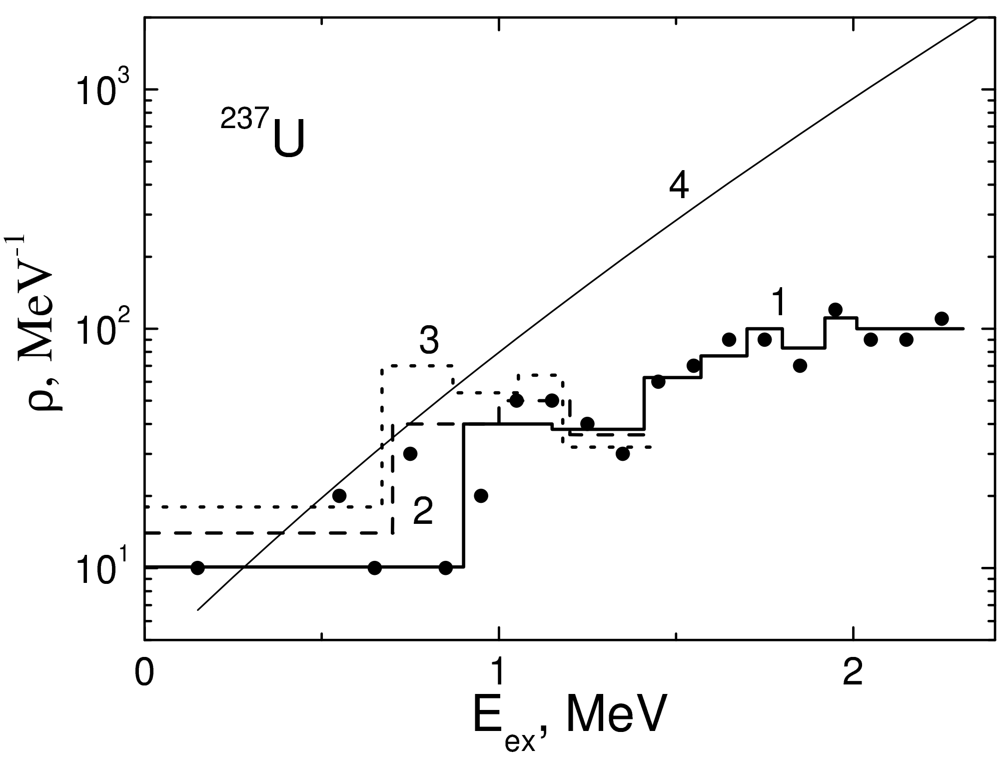

Fig. 6. The same, as in Fig. 4, for the density of excited levels. Line 4 represents calculation within model [22] for spin values J=1/2 and 3/2. Points correspond to number of levels observed in resolved resonances.

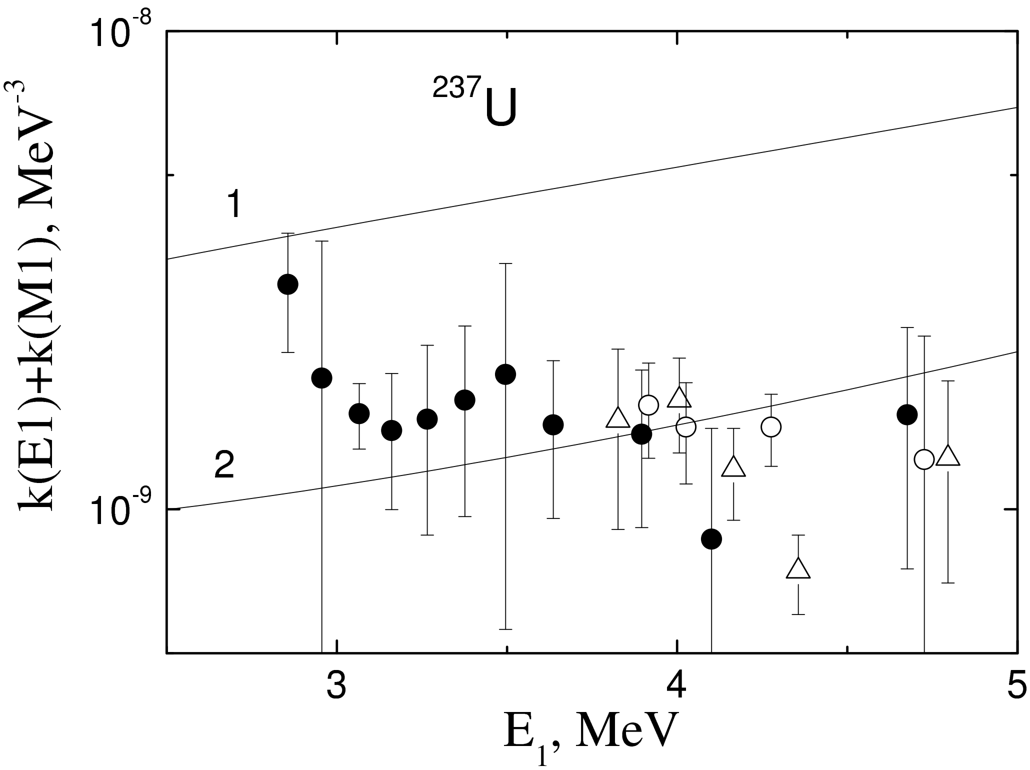

Fig. 7. The summed radiative strength functions derived from the data on capture of neutrons with different energies E_n: black points – $5 < E_n < 125$ eV, open points – $E_n \approx 2$ keV, triangles – $E_n \approx 24$ keV. Line 1 represents calculation within model [5], line 2 – calculation within model [23] together with k(M1)= const.

3.1 Some sources of systematic errors

Absolute minimum of χ^2 for all used sets of intensities is achieved practically for the only N_γ value. Change in this parameter by ± 1 brings to significant increase in χ^2. This allows one to neglect possibility of considerable (for example, 10-20%) error of determined level density.

Main problems in determination of nuclear parameters and their systematic errors, most probably, are stipulated by:

(a) the use of assumptions on the distribution form of the random intensity deviations from the unknown mean value and

(b) possible presence of significant errors in the set of the intensities under analysis.

1. The Porter-Thomas distribution allows very considerable random deviations of partial widths. But the measured gamma-transition intensities are always limited by finite value of the total radiative width of decaying state. Therefore, the set of the best values of parameters depends on the total width of region for approximation of cumulative sums. Mainly this concerns the best value of parameter ν. In the performed analysis, intensities were normalized so that their maximum value would not exceed 50-70% of the approximation region width.

2. The main error of analysis can be related only to the "loss" of gamma-transitions whose intensities exceed threshold value and/or due to mistaken identification of the secondary gamma-transitions as the primary one. The probability of overlapping of two peaks corresponding to neighbouring levels was estimated in [24]. As it follows from the data presented by authors, this effect is rather small and, most probably, cannot explain considerable (several times) discrepancy between level density determined by us and predictions of the Fermi-gas level density model [22].

Considerable uncertainty could be due to even and significant loss of observed peaks corresponding to intense primary transitions (exceeding their detection threshold) owing to their grouping in multiplets with rather narrow ($\sim 1-2$ keV) spacing between peaks. But this possibility is not predicted by modern nuclear models.

3. In principle, there is possible the situation when gamma-transitions in all or larger part of chosen intervals of primary transition energies (with the width of some hundreds keV) have different mean values. Moreover, probability of relatively low-intense transitions strongly but smoothly increases as decreasing their intensities. Potentially, this effect can be due to by fragmentation mechanism of states over concrete neighbouring nuclear levels.

Apparently, only such hypothesis can be alternative potential explanation of "step-wise" structure in level density in analysis performed in this work. Application of this hypothesis to the level densities determined according to [3, 4] requires that the main portion of levels with the same J^π below $\approx 0.5B_n$ would not be excited by the primary gamma-transitions. Besides, some Cooper nucleon pairs would break simultaneously at low in comparison with B_n nuclear excitation energy. We cannot suggest other possibility for precise reproduction of the two-step gamma-cascade intensities in calculation.

3.2 Interpretation of the obtained results

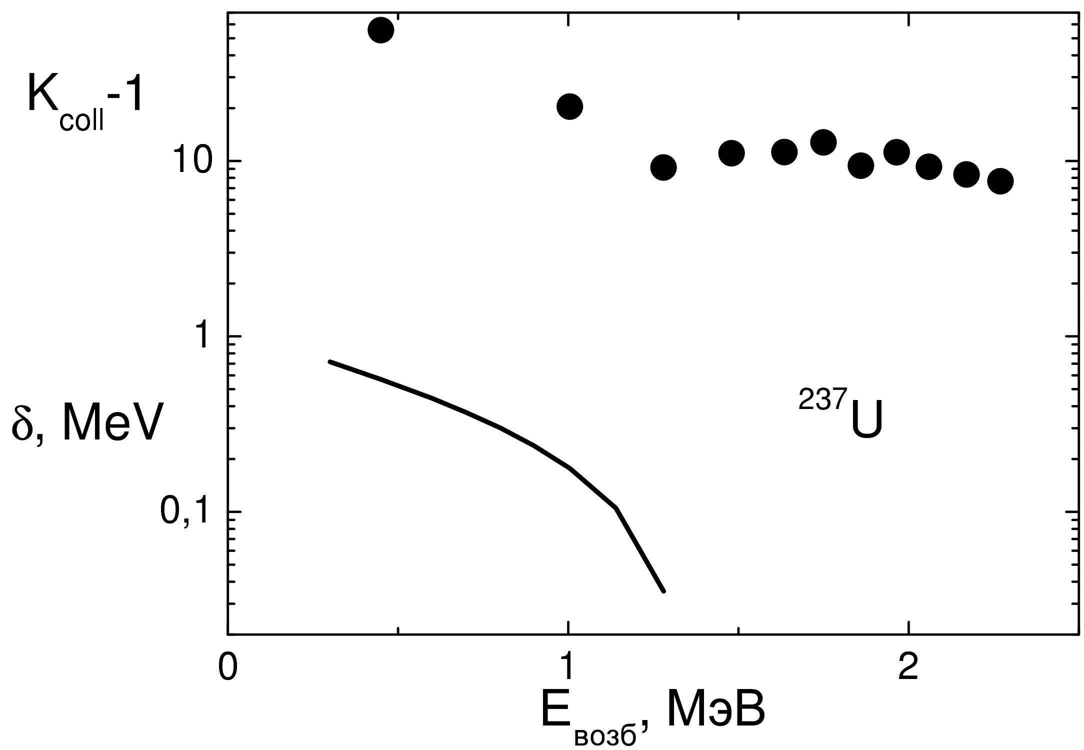

Fig. 8. The points represent the coefficient of collective enhancement of level density, the line shows the values of parameter δ_1 used in [3, 27] for calculating partial density of three-quasiparticle levels.

The physics important information on level structures below $\approx 0.5B_n$ can be extracted from the values of coefficient of collective enhancement of level density:

$$\rho(U, J, \pi) = \rho_{\text{qp}}(U, J, \pi) K_{\text{coll}}(U, J, \pi). \quad (1)$$

According to modern notions, K_{coll} determines in deformed nucleus [1] a degree of enhancement of level density of pure quasi-particle excitations $\rho_{\text{qp}}(U, J, \pi)$ due to its vibrations and rotation. In very narrow spin window considered here one can accept in the first approach that, to a precision of small constant coefficient, it equals coefficient of vibration increase in level density K_{vibr}. On the whole, the last is determined by change in entropy of a nucleus δS and redistribution of the nuclear excitation energy δU between quasi-particles and phonons at nuclear temperature T:

$$K_{\text{vibr}} = exp(\delta S - \delta U/T). \quad (2)$$

The experimental data at hand on level density and existing model notions of it do not allow one unambiguous and reliable determination of the $K_{\rm vibr}$ value for arbitrary nuclear excitation energy U even at zero systematic error in determination of function $\rho(U, J, \pi)$.

Now is no possibility for ambiguous experimental determination [25] of breaking threshold E_N of the first, secondary and following Cooper pairs, value and form of correlation functions δ_N of Cooper nucleon pair number N in heated nuclei. The main uncertainty of E_N is caused by the lack of the experimental data on function $\delta_N = f(U)$, the secondary – by uncertainty of level density of single-particle levels g in model [26]. So, in three different, model dependent approximations of level density in large set of nuclei of different type [25] and [27], the threshold E_2 of five-quasi-particle excitations differs by a factor of 1.5-2.

In practice, for estimation of K_{vibr} from the data [21] we used the second variant of notions of correlation function of Cooper pair in heated nucleus [25]. In calculation were used the values δ=0.83 MeV, g=14 MeV^{-1}. The best value of breaking threshold for the first Cooper pair was found to be equal to $E_1 = 0.55$ MeV when using the assumption on independence of K_{vibr} on nuclear excitation energy. At low excitation energy this assumption is, most probably, unreal (see Fig.8).

Parameter $K_{coll} - 1$ determined from comparison between the calculated in this way density of three-quasiparticle excitations (J=1/2, 3/2) and its most probable experimental value is shown in Fig. 8 together with calculated value of δ_1.

Significant correlation of this coefficient with δ_1 from [27] and from the second variant of the analysis [25] is observed in the excitation energy interval below approximately 1.2 MeV. At higher excitation energy, decrease in degree of correlation can be related to both considerable contribution of five-quasiparticle excitations in the function $\rho_{qp}(U, J, \pi)$ and less than it is accepted in [25, 27] rate of function δ_1 at $U > 1.2$ MeV.

The data presented permit one to make the following conclusions:

1. The study of the ^{237}U nucleus excited in reaction $(\overline{n}, \gamma)$ by neutrons with energies 0.005-0.12, 2 and 24 keV allow us to observe the same properties as those revealed for ~ 40 nuclei from the mass region $40 \leq A \leq 200$. There are: step-wise structure in level density and local enhancement of radiative strength functions of the primary gamma-transitions to corresponding levels.

2. In the excitation energy region about 0.7-1.5 MeV occurs abrupt change in level structures. This appears itself in considerable enhancement of the $k(M1)/k(E1)$ values and in strong difference of their distribution from normal distribution of random amplitudes of gamma-transitions.

3. Experimental ratios $k(M1)/k(E1)$ can be used for obtaining more unique values of strength functions of E1- and M1-transitions and data on relations between density of levels with different parity in the frameworks of methods [3, 4].

4. The majority of the primary gamma-transitions observed in reaction $(\overline{n}, \gamma)$ correspond, probably, to excitation of levels with large and, maybe, weakly fragmented phonon components of wave functions.

4 Conclusion

Analysis of the available experimental data on the primary gamma-transitions from reaction $(\overline{n},\gamma)$ in compound nucleus ^{237}U has demonstrated step-wise structure in level density and increasing radiative strength functions of transitions to levels lying in the region of this structure, at least, for the primary dipole transitions. I.e., it confirmed main conclusions of [3, 4]. It showed also a necessity to reveal and remove systematic errors of experiment in alternative methods for determining only level density and simultaneously – all the parameters of the cascade gamma-decay. Very important for this are both correct accounting for effect of level structures on probability of emission of evaporated nucleons and cascade gamma-quanta in investigation of nuclear reactions at beams of accelerators and considerable reduction of systematic errors of experiment.

Abrupt increase in dispersion (decrease in the ν parameter) of random deviations of intensities from the mean (expected according to [10]) values allows one to suppose the presence in their structure of considerable components of weakly fragmented nuclear states being more complicated than the three-quasiparticle states. Approximation of the obtained level density by Strutinsky model confirms considerable ($\approx$ 10 times) increase in level density due to excitations of mainly vibration type [27]. Comparison of the data presented in figs. 6, 7 with those obtained from analysis of two-step gamma-cascades permits one to make preliminary conclusion that the sharp change in structure of decaying neutron resonances, at least, in their energy interval $\approx$ 24 keV is not observed. And there are no reasons to expect serious change in determined according to [3, 4] level density and shape of energy dependence of radiative strength functions for the primary gamma-transitios from resonance to resonance. Further reduction of systematic errors of these nuclear parameters determined from the two-step gamma-cascade intensities undoubtedly requires reliable estimation of functions $k(E_\gamma, E_{ex})$ for all energy interval of levels excited at neutron capture.

The analysis performed in this work and its results point to necessity of experimental determination of ρ and k by the method [4] in all practically important for nuclear energetics nuclei from the region of actinides.

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