Two Regions of a Possible Drastic Change in the Structure of the Excited States of Any Nuclei

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From a comparison of the absolute intensities of individual two-step cascades with known intensities of their primary and secondary transitions following thermal neutron capture the cascade and total population abilities of up to ∼ 100 levels of each of the nuclei: 40K, 60Co, 74Ge, 114Cd, 118Sn, 124Te, 137,138Ba, 150Sm, 156,158Gd, 165Dy, 168Er, 175Yb, 181Hf, 183,184,185,187W, 196Pt and 200Hg have been determined. These experimental data as well as the intensities of two-step cascades to the low-lying levels of these very nuclei can be restored within an accuracy of experiment if only the level densities with a clearly expressed "step-like" structure are used and a considerable local increase of the radiative strength functions of secondary transitions to the levels situated close to the breakpoints on the energy dependence curve of level densities and their quite significant decrease to the low-lying levels of the nucleus are taken into account.

INTRODUCTION

The chief goal of experimental and theoretical investigations in low energy nuclear physics is the creation of a consistent model representation of the properties of nuclei in a specified interval of their excitation energy. A set of such models will provide an experiment-commensurable accuracy of the calculation of any practice-important parameters of the nucleus. To solve the problem, experiment must provide theory with a complex of experimental data that would reflect, in a quite explicit way, the most important properties of nuclear matter. In practice, it is necessary that the density of the excited levels of nuclei in a specified interval of their quantum numbers over the entire investigated region of their excitation energy together with the emission probability of the products of the corresponding nuclear reaction should be determined. If the investigation is restricted to the binding energy of the nucleon in the nucleus, the main product of the nucleon capture reaction is gamma-quanta and the parameters determined are their radiative strength functions.

In nuclei with a sufficiently high density of excited levels (ρ > 10³ MeV⁻¹) it is practically impossible to single out an arbitrary gamma-transition and determine the situation of the levels it links. This is why classical nuclear spectroscopy cannot solve the discussed problem. However, neither the purposes of the development of nuclear theory nor of applied research require such detail information. It quite suffices to determine experimentally the averaged parameters of the nucleus: the density of levels and the radiative strength functions of the gamma-transitions it emits. Unfortunately, experimentalists have not been able to find a universal precise solution to the problem so far.

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What seriously complicates the solution of the problem is that the intensity of the spectra of evaporative nucleons [1] and of primary gamma transitions emitted in nuclear reactions as excited levels with some arbitrary energy $E_{ex}$ discharge [2] does not depend, in any way, on the absolute values of the level density and emission probability of evaporative nucleons and gamma-quanta.

The situation has radically changed after procedures for the determination of the intensities of two-step cascades as a function of the energy of their primary gamma-transition [3]:

$$I_{\gamma\gamma} = \sum_{\lambda,f} \sum_i \frac{\Gamma_{\lambda i}}{\Gamma_\lambda} \frac{\Gamma_{if}}{\Gamma_i} = \sum_{\lambda,i} \frac{\Gamma_{\lambda i}}{\Gamma_{\lambda i} > m_{\lambda i}} \frac{\Gamma_{if}}{\Gamma_{if} > m_{if}},$$

connecting the neutron resonance and specified low-lying levels of the studied nucleus and those for the extraction [4] from the data on the density of levels $\rho$ and radiative strength functions

$$k = \frac{\Gamma_{\lambda i}}{(E_\gamma^3 \times A^{2/3} \times D_\lambda)}$$

of cascade gamma-transitions, were developed. The value of $I_{\gamma\gamma}$ is determined by the ratio of the partial widths of the primary $\Gamma_{\lambda i}$ and the secondary $\Gamma_{if}$ gamma transitions between the levels $\lambda$, $i$ and $f$ to the corresponding total radiative widths and by the number of levels, $m$ and $n$, excited in the different intervals of their energies. At the same time, their combination ensures (sooner qualitatively) the proportionality of the intensity to $\rho^{-1}$ and in this way, maximum sensitivity of the experiment to minimum level density values.

Since the difference between the spins of primary and final levels is not, as a rule, larger than 2, the value of $I_{\gamma\gamma}$ at thermal neutron capture is practically determined by only dipole transitions and level densities in unambiguously established intervals, $J^\pi$.

By now, the intensities of thermal neutron capture two-step cascades for all possible gamma-quanta energies have been measured for 51 nuclei from $^{28}\text{Al}$ to $^{200}\text{Hg}$ with coincidence spectrometers in Dubna, Riga, and Řež. For 40 of them, from the experimental spectra there was determined the portion of intensity that corresponds to the specified intervals of primary gamma-transitions by applying the procedure [3].

Though the number of unknowns in Eq. (1) is always larger than the number of the measured experimental values, the form of the dependence $I_{\gamma\gamma}$ on its determining parameters allows the separation of finite (and rather small) intervals of their values using which one can reproduce the experiment quite precisely. Naturally, the procedure [4] employs additionally known total radiative widths as well as known densities of low-lying levels and of neutron resonances.

A quite essential regularly observed difference between the observed and the calculated for 51 nuclei distributions of cascade intensity with the total energy $E_1 + E_2 = B_n - E_f$ (if the energies of their final level $E_f < 1$ MeV) shows that the existing representations and models of cascade gamma-decay need to be seriously corrected. We could not find any other possibility to make the accuracy of the model calculation of the cascade gamma-decay of any nucleus approach that of the present day experiment.
From analysis of all the data yielded by studies of two-step cascades (especially on the radiative strength functions of cascade transitions $k$ and on the density of the levels excited by them $\rho$ obtained in accordance with [4]) it follows that the structure of the wave functions of the excited levels is essentially different for their energy regions below and above $\sim 0.5B_n$. In the framework of today’s theoretical representations of the dependence of the level density on the excitation energy of the nucleus the difference can be only explained (mainly qualitatively) as being due to the breakup of coupled nucleons. Consequently, the level density and the probability of their excitation (discharge) differ significantly from those predicted on the basis of model representation of the nucleus as a purely fermion system (for example,[5,6]).

The importance of the conclusion comes from the fact that such model representations of the nucleus continue to be used today to analyze the experiment and to calculate gamma-spectra and neutron-nucleus interaction cross sections. At the same time, the specific character of the data obtained in [4] together with analysis of the conditions of the corresponding experiment calls for going over not only to more realistic models of level density $\rho$ and radiative strength functions (2) (in a manner that would maximally reduce their dependence on the mass of the nucleus $A$) (of the type [7,8] and [5,9], respectively), but also to their more precise parameterization and further development. The necessity of further mathematical developments is not only due to insufficient agreement between model representations and the experiment but is also due to demand for a more precise interpretation of processes occurring in the nucleus.

1 THE POSSIBILITY OF RELIABLE DETERMINATION OF $\rho$ AND $k$ IN THE PRESENT-DAY EXPERIMENT

Ordinary HPGe-detectors (relative effectiveness not higher than 30%, no anti-Compton shielding) on a thermal neutron beam make it possible to obtain, in a period of 300 – 700 hours of the experiment, the cascade intensity distribution as a function of the energy of the primary transition in the cascade for the final levels with the excitation energy $E_f$ not higher than 1 MeV within an acceptable error and to determine the total intensity of two-step cascades to the upper lying levels with $E_f$ up to $\approx 2$ MeV. This means to observe in the experiment, in the form of extremely simple and very convenient for analysis spectra of $\sim 50$ to $\sim 95\%$ total intensity primary gamma-transitions at discharge of excited compound-states.

This allows obtaining of detail, precise and reliable information on the process of cascade gamma-decay on thermal neutron capture in any stable target nucleus. First of all, it is the density of the intermediate levels of the cascade and the radiative strength functions of cascade gamma-transitions. Unfortunately, however, $\rho$ and $k$ obtained in accordance with [4] contain some unknown systematic error whose ordinary part is determined by inaccuracies of neutron capture cross sections, measured gamma-quanta intensity in radiative thermal neutron capture spectra, particular experimental conditions of gamma-gamma coincidence registration, etc.

In the present stage of technique development [4] the specific part of the systematic error is determined
by possible existence of dependence of the strength function not only on the energy $E$ of a specified multipolarity quantum but also on the excitation energy $E_{ex}$ of the decaying level, not accounted for in [2] and [4], i.e., by the existence of the function $k = F(E, E_{ex})$ in place of the assumption that $\Gamma_{if}/\Gamma_i = F(E)$ made when Eq. (1) was derived.

The ordinary part of the determination error of $I_{\gamma\gamma}$ in the present-day experiment can be easily minimized to the level not exceeding 5-20%. The specific part determines the difference, that is non-removable or difficult to remove today, between the extracted from experiment and real $\rho$ and $k$. In principle, the difference can be completely removed by measuring the intensities of two-step cascades to final levels with energies not lower than 3-5 MeV (depending on the type of the investigated nucleus). To do this, one can use multi-detector systems of HPGe-detectors whose number can even be limited.

The possibility of estimation of the effect of the decaying level energy $E_{ex}$ on the relative value of the radiative strength functions of gamma-transitions of equal multipolarity and energy does exist at present. For all the investigated nuclei there is obtained a considerable volume of information about the intensities

$$i_{\gamma\gamma} = i_1 \times i_2 / \sum i_2,$$

that are energy-resolved in the spectra as pairs of peaks of individual cascades. Their parameters, including the most probable quanta ordering, are reliably extracted from the experiment up to the cascade intermediate level excitation energy 3-5 MeV with the help of an original technique of analysis created in Dubna that employs a numerical algorithm of resolution improvement providing for a maximum possible resolution of all the obtained spectra $E_1 + E_2 = \text{const}$ without loss of effectiveness [10].

For $^{181}\text{Hf}$ and even-odd isotopes of $\text{W}$, most complete intensity spectra of primary, $i_1$, and secondary, $i_2$, gamma-transitions emitted on thermal neutron capture were also measured up to $B_n$ in Riga and Rež [11]. The spectra of targets made of elements with a natural isotopic composition are given in [12]. The most fresh data on $i_1$ and $i_2$ are in the file “EGAF” [13] in the amount that allows obtaining of quite acceptable (though rather insufficient in volume) information on the discussed value for the nuclei $^{40}\text{K}$, $^{60}\text{Co}$, $^{74}\text{Ge}$, $^{114}\text{Cd}$, $^{118}\text{Sn}$, $^{124}\text{Te}$, $^{137,138}\text{Ba}$, $^{150}\text{Sm}$, $^{156,158}\text{Gd}$, $^{165}\text{Dy}$, $^{175}\text{Yb}$, $^{190}\text{Pt}$ and $^{200}\text{Hg}$.

Unfortunately, a limited volume of data on radiative thermal neutron capture spectra does not permit deriving of somewhat significant information for the rest 30 nuclei from the analysis discussed below. Among these nuclei, in the first place, are compound spherical and deformed odd-odd nuclei of middle mass.

## 2 METHOD OF DETERMINATION OF CASCADE POPULATION OF LEVELS

From Eq. (3), taking advantage of the presently available data on $i_{\gamma\gamma}$, $i_1$ and $i_2$ the total population $P = \sum i_2$ of about 100 levels can be determined for the majority of the above enumerated nuclei to their excitation
energy 3-4 MeV and higher. The difference between $P$ and the intensity $i_1$ of primary transitions to each of the levels is equal to the sum of their population by 2-, 3-, etc.-quantum cascades. It can be calculated in various ways if certain assumptions are made about the density of levels excited on thermal neutron capture and strength functions of cascade gamma-transitions. To this end, there can be used, for example, the existing model representations of densities and strength functions as well as possible hypotheses about them (including the values of $k$ and $\rho$ obtained in accordance with [4]). Then the areas of maximum divergence of the experiment from the different calculation variants would show where and in what direction the model description of the cascade gamma-decay process should be modified. Since at present, there is practically no possibility to determine experimentally the population of all, without exception, intermediate levels of two-step cascades even at their moderate excitation energies (due to the existing threshold of registration of the intensities $i_{\gamma\gamma}$, $i_1$ and $i_2$), it is reasonable to perform an experiment to calculation comparison for $P - i_1$ summed over a small interval of excitation energies. Such sums should be looked at as a lower estimate for each of the intervals. We can make such a comparison for all of the enumerated compound nuclei. Simultaneously, the dependence of the intensity of two-step cascades on the energy of their primary transition $E_1$ is reproduced.

In the present-day experiment [11-14], the error of $i_1$ and $i_2$ is limited by errors within which the cross section of thermal neutron capture in the investigated isotope are known [15]. In most cases it is not higher than 5-10%. Accordingly, the population of any level from Eq.(3) has an accuracy that is only determined by the systematic error of the data [11-14], random error of particular $i_1$ and $i_2$ and in addition, by errors of determination of gamma-quanta intensities in the HPGe-detector spectra due to partial overlapping of the peaks because of a limited resolution of the spectrometer. The portion of such cases can be reduced several times, by a maximum factor of 25%, by careful approximation of neutron capture gamma-spectra in a practically monoisotopic target using the data on resolved two-step cascades.

To calculate $P - i_1$, the number of the dependence function variants of the strength functions and the density of levels on the gamma-quanta energy and the level excitation energy can be infinitely large. However, the general regularities of changes in the level population with their changing excitation energy can be determined using just three calculation variants:

a) The density of levels is predicted by any variant of the model of a noninteracting Fermi-gas, the strength function of E1-transitions is specified by known extrapolations of the giant electric dipole resonance in the region below $B_n$, and $k(M1) = const$ is specified by the normalization of $k(M1)/k(E1)$ to the experiment around $B_n$;

b) $\rho$ and $k$, that are obtained in accordance with [4] and reproduce exactly the intensity of two-step cascades as a function of energy of their primary transition, are used (at present, only for the final levels in the cascades with $E_f < 1$ MeV);

c) A set of level density and strength function values is chosen to reproduce exactly ($\chi^2/f << 1$) the values of $I_{\gamma\gamma} = F(E_1)$ (Fig. 1), the total radiative width $\Gamma_{\gamma}$ of the decaying compound state and the values
of \( P - i_1 \) at the same time.

The realization of the variant c) is possible in the iteration mode: for \( k \) obtained in accordance with [4] there is selected some dependence function that would change the secondary gamma-transition strength function values with respect to that of the strength function obtained in accordance with [4] to enable the best reproduction of \( P - i_1 \). To this end, it suffices to multiply the strength functions of the secondary gamma-transitions to the levels below some boundary excitation energy \( U_{2 \text{max}} \) by the function \( h \) containing several narrow peaks. The dependence of their behavior on the excitation energy of the nucleus can be determined by analogy with the specific heat of ideal macrosystems in the second-order phase transition point as:

\[
h = 1 + \alpha \times (\ln(|U_c - U_1|) - \ln(|U_c - U|)) \quad \text{if} \quad U < U_c, \tag{4}
\]

\[
h = 1 + \alpha \times (\ln(|U_c - U_2|) - \ln(|U_c - U|)) \quad \text{if} \quad U > U_c, \tag{5}
\]

with some parameters \( \alpha, U_1, U_2, U_c \). The condition \( (U_c - U_1) \neq (U_2 - U_c) \) ensures the necessary symmetry of the peaks and enables a somewhat more precise reproduction of the cascade level population at the tail-ends of the peaks in comparison with a Lorentz curve, for example.

In the best variant tested by us, the amplitude \( \alpha \) must grow (linearly, for example) as the excitation energy \( U \) decreases from zero at \( U = B_n \) to the maximally possible value shown in Figs. 2,3. The situations of the peaks, their amplitude and form are determined quite unambiguously by \( P - i_1 \). The population of any level whose number is \( l \) is determined by the equation:

\[
P_l = \sum_m P_m \times \frac{\Gamma_{m,l}}{\Gamma_m}, \tag{6}
\]

that depends on the population of all \( m \) upper lying levels and on the branching coefficient of their decay. Although the data on the population depend on the two factors in the equation, the value of \( P \) for the different low-lying levels is mainly determined by the relationship between the partial widths of the secondary transitions exciting them. Eq. (6) gives no other possibility to ensure an essential increase in the population of higher-lying levels.

The determined correcting functions are then included in the analysis [4] for the determination of \( \rho \) and \( k \) that exactly reproduce the cascade intensities taking into account an assumed difference between the energy dependence of the strength functions of the primary and secondary transitions in the cascade. The values of \( I_{\gamma \gamma} \) are illustrated in Fig. 1 and the re-determined level densities and strength functions are shown in Figs. 2,3. If necessary, the cycle is repeated once at most if the hypothesis of linearly growing distortions in the value of \( k(E1) \) and \( k(M1) \) with increasing energy of the decaying levels is used and several times in case the hypothesis of \( \alpha = \text{const} \) is employed. To minimize the number of the parameters to be selected, the correcting functions (4,5) are assumed to be similar for electric and magnetic gamma-transitions. For the analyzed nuclei, the most general regularities in the behavior of the function \( h \) retrace sufficiently well
analogous dependence curves in [18]. In other words, there is observed a considerable increase of $k$ in the region of "step-like" structures and their considerable decrease for gamma-transitions to the low-lying levels.

The use of a large number of hypotheses is inevitable in the achieved stage of the problem being solved. In this case, all the conclusions about the cascade gamma-decay process of the compound state should be considered as qualitative rather than quantitative. So, the existence of a clearly expressed "step-like structure" of the level density and the related increase in $k(E1) + k(M1)$ (Fig. 2) can be considered as established with a high probability. However, the number and the form of such "steps" may be only determined in further experiments. The same is true about the parameters of the correcting function $h$. Though the situation of the excitation energy region to which an essential increase in $k$ for 2nd-, 3rd-, etc.-transitions in the cascade corresponds causes no doubt (thanks to the number of tested variants), the particular parameters of the function $h$ should rather be considered as particularly preliminary and be used, in the first place, for the development of refining experiments.

3 THE BEHAVIOR OF THE DEPENDENCE OF THE BEST $k$ AND $\rho$ ON THE ENERGY OF THE DIPOLE GAMMA-TRANSITION AND THE EXCITATION ENERGY OF THE NUCLEUS

The realized method for the determination of $\rho$ and $k$ enables obtaining of their precise and reliable values employing practically no models. Unfortunately, besides the analyzed sources of a possible systematic error, the $\rho$ and $k$ values may contain additional errors different for particular nuclei. For example, the absolute value of $k$ may have distortions due to some local deviation of the density of neutron resonances $\rho = D^{-1}_\lambda$ from its basic tendency or due to possible, though not accounted for in Eq. (1), structural effects. This may be correlation between the partial radiative widths of cascade transitions and reduced neutron width of the resonance, that determines the basic part of the thermal neutron capture cross section.

The effects of those factors can be reduced by averaging radiative strength functions separately over even-even, even-odd and odd-odd compound nuclei. In the process of averaging there must be taken into account a rather strong difference between neutron binding energies in the investigated nuclei and very strongly differing dependence of the level density on the excitation energy of the nucleus. In the variant suggested below, $B_n$ equals unity for each of the nuclei and the level density is taken in the form of its relationship with the simplest interpolating function $\text{const} \times \exp(\kappa E_{ex})$, whose parameters are fully determined by the densities of neutron resonances and levels in the excitation energy region around 1-2 MeV. Since $k$ presented by (2) depends weakly on the mass of the nucleus, the sum of the strength functions of dipole transitions is directly averaged over nuclei with equal parity of nucleons. The averaging is performed for a set of a larger part of 40 nuclei for which $\rho$ and $k$ are determined by the method [4] as well as for the nuclei whose
population of individual levels is determined. As it is seen from Fig.4, in the first and the second variant the energy dependence \(k(E_1) + k(M1) \approx \text{const}\) for the primary transitions with \(E_1 < 0.3B_n\) independently of the nucleus type. This confirms the principal validity of the basic representations of the model [3] for gamma-transitions from the compound states of high-lying levels. For odd-odd nuclei, however, strength functions are 2-3 times larger than similar data on Z-even nuclei. Maximal possible values of \(k(E1) + k(M1)\) are observed in the region \(E_1 \approx (0.7 - 0.8)B_n\) and they decrease as the primary transition energy further increases.

As it is seen from Fig. 5, the function \(R = \text{const} \times \rho \times e^{\alphaE_{ex}}\) has maximums in the region of \(E_{ex} \sim 0.2\) and \(\sim 0.8B_n\) and a minimum at about \(0.5B_n\). From a comparison of two variants of the data for odd-odd nuclei (Fig. 5) it can be expected that their situations change as the mass of the nucleus changes (the population is only determined for \(^{40}\text{K}\) and \(^{60}\text{Co}\) ) and most of \(\rho\) and \(k\) values are obtained for heavy deformed nuclei. In the analysis [4], as it is accepted in such calculations, the entire excitation region of a particular nucleus is divided into “continuous” and “discontinuous” parts (with known scheme of decay). It also envisages the possibility of local variations of \(k\) on the basis of experimental cascade intensity “jumps” (Fig. 1). This leads to the appearance of “breakups” in the functional dependence in Figs. 2 and 3.

A sufficiently general type of the dependence of the discussed parameters for nuclei having the different parity, \(N\) or \(Z\), makes it possible to conclude that the extraction technique of \(\rho\) and \(k\) from the intensities of two-step cascades (employing data on the cascade population of levels in the nucleus) allowing one to uncover the most general properties of the investigated parameters of the nucleus.

From the data in Fig. 5 it follows that in any type and/or mass nuclei (except for some nuclei) there exist at least two regions of excitation with a heightened density of levels. In spite of the common nature of how the regions demonstrate themselves, some additional modulation of radiative strength functions of the type shown in Figs. 4 and 5 can be assumed to exist at high excitation energies as well. One can then assume, by analogy with Figs. 4 and 5, that more precise radiative strength functions of secondary transitions in the cascade should ensure more exact reproduction of the data in Fig. 1. This is especially important for well-deformed even-even nuclei for which the amount of the experimental data on the population of levels and the expected changes in strength functions is rather limited.

It should be noted that the conclusion made concerning a local increase of the radiative strength functions of the secondary gamma-transitions to the levels in the area of the ”step-like” structure of the level density makes it possible to reproduce not only the basic peculiarities of the cascade population of levels below 3-4 MeV but also the dependence \(I_{\gamma\gamma} = F(E_1)\) using practically similar dependence functions \(\rho = \phi(E_{ex})\) and \(k = \psi(E_1)\) for the different nuclei. At the same time, their divergence from the existing models is much more expressed in comparison with [4] (Fig. 4).

The presented results should be looked at as a preliminary and, to some extent, qualitative description of the processes occurring in the nucleus. They cannot claim to be a complete and whole reproduction of the experimental picture of the cascade gamma-decay process because:
a) the hypotheses and model representations used in Eq. (1) may be inadequate to the experiment;
b) it is impossible to determine the number \( N \) of the observed intermediate levels in the cascade with an error less than several tens of percent in the experiment performed for only one compound state (does not make it possible to exclude or estimate the degree of correlation between the neutron width of the compound state and partial radiative widths of secondary transitions);
c) it is impossible to estimate the total cascade population of the levels for which the value of \( i_{\gamma\gamma} \) lies below the registration threshold and/or of the intermediate levels for which \( i_1 \) and \( i_2 \) are unknown.

In spite of the above restrictions it is possible to conclude that the basic properties of the observed cascade decay process can be only reproduced within the framework of models that assume the existence of a considerable local increase of the radiative strength functions of gamma transitions to the levels lying in the interval with the width \( \sim 1 \) MeV in the vicinity of the effective excitation energy of a heavy deformed nucleus, 3-4 MeV.

4 CONCLUSION

The attribute of the second-order phase transition is a sharp change of the internal properties of the investigated system as its energy changes. While quite a sharp change of the level density (i.e., of the thermal capacity of the nucleus, in fact) was earlier established experimentally in [4] with a sufficiently high reliability, the results of the performed analysis point to a sharp change of the reduced probability of gamma-transitions (primary, at least) in some, rather narrow, region of the levels of any nucleus excited by them.

The above reported results, that point to an essential increase in the radiative strength functions of secondary gamma-transitions for practically the same region of energies, can be considered as an additional independent proof of the existence of some region of excitation energies in the nucleus where a sharp change in the structure of the nucleus takes place. Presumably, it is a transition from domination of vibrational excitations to that of quasiparticle ones. Apparently, this can be interpreted as a phase transition from superfluid to ordinary state of such a specific system as nucleus. The effect is possibly associated with a breakup of the only pair of nucleons at excitation energies corresponding to a sharp decrease in the level density.

The whole set of the presently available data about the cascade gamma-decay of compound states excited on thermal neutron capture allows the conclusion that below the neutron binding energy a sharp change in the structure of the excited levels is observed at two excitation energies at least (Fig. 5). The extrapolation of the conclusion to the region of high excitation energies results in the necessity of precise determination of level density using non-model independent procedures at high excitation energies as well.

Today, the data obtained as a result of the investigation of the nucleus in the discussed region of excitations
should be rather considered as a preliminary indication to the possibility of the existence of such a transition. The quantitative information could be of use for planning of a more detail experiment to solve the discussed physical problem - a direct experimental investigation of the dynamics of the breakup of Cooper pairs in various finite nuclear systems dissimilar in the type of statistics and in their energy with respect to the Fermi surface.
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Fig. 1. The examples of the intensity of two-step cascades as a function of their primary transition energy averaged over the intervals of the primary transitions energy $E_1$ with a width of 0.5 MeV for the nuclei $^{40}\text{K}$, $^{60}\text{Co}$, $^{74}\text{Ge}$, $^{114}\text{Cd}$, $^{137}\text{Ba}$, $^{150}\text{Sm}$, $^{156}\text{Gd}$, $^{158}\text{Er}$, $^{181}\text{Hf}$, $^{184}\text{W}$ (renormalized to the data [13]), $^{196}\text{Pt}$ and $^{200}\text{Hg}$. Curve 1 - calculated by Eq. (2) for the models [4] and [16,17], Curve 2 - [5,6].
Fig. 2. The points with errors - the sums of the radiative strength functions of the dipole electric and magnetic transitions in the cascade allowing precise reproduction of their intensities for the investigated difference of their values from the strength functions of the secondary transitions (multiplied by $10^9$). Open circles - similar values for the case of $\hbar = 1$. Curve 1 (upper) - predicted by the model [16], lower – [5] under the assumption that $k(M1) = \text{const}$ [17]. Curve 2 - the maximum value of the function $h$ for the secondary gamma-transitions to the levels $E_i$. 
Fig. 3. The points with errors - the total number of all intermediate levels in two-step cascades, that reproduces the whole set of the experimental data as a function of the intermediate level energy of the cascade. Points - similar values for the case of $h = \text{const}$, the upper thin curve - predicted by the model [6]. The thick curve - the best value of the function $h$. Triangles - the observed number of intermediate levels in resolved cascades.
**Fig. 4.** A comparison of the mean sums of the radiative strength functions of nuclei with the different parity of the number of neutrons and protons. Dark circles with errors - only nuclei for which the level population is determined. Open circles - all the nuclei for which the analysis [4] is performed without accounting for the difference between the energy dependence of the strength functions of the primary and secondary transitions. Upper curve - predicted by the model [16], lower curve [5] under the assumption that $k(M1) = \text{const}$.
Fig. 5. Mean relative variations of the level density. The notation is similar to that for Fig. 5.