# THE POSSIBILITY FOR EXPERIMENTAL DETERMINATION OF INTERACTION CROSS-SECTION OF NUCLEON WITH EXCITED NUCLEUS

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**Abstract**

By means of the experimental data on level density of even-odd tungsten isotopes determined in the $(n, 2\gamma)$ reaction, the ratio between interaction cross-section of excited nucleus with neutron and its value calculated within nuclear optical model was obtained from the spectra of evaporated neutrons of the $^{181}\text{Ta}(p, n)^{181}\text{W}$ reaction. The obtained considerable local enhancement of this parameter is qualitatively interpreted as possibility of increase in penetration of nuclear surface due to influence of phonon-type excitations. There are considered the sources of possible, but not rejected systematical errors of experimental determination of level density of arbitrary nucleus below the neutron binding energy $B_n$, as well. There has been modeled the process of information extraction from the cascade intensity distributions of type "nucleon and gamma-quantum". The use of all the totality of the experimental data on the nucleus under study can provide for very high reliability of the obtained information.

## 1 Introduction

Experimental investigation and following theoretical analysis of superfluidity of heated nucleus offer new of principle possibilities for understanding of of the process of interaction and mutual transition of the Fermi and Bose quantum systems. The main parameter of this analysis is level density $\rho$ of excited nucleus and determining its value entropy of nuclear matter [1]. The last survey of the existing by now notions of level density is presented in [2]. In order to obtain reliable picture of the process under study it is necessary to determine density of excited levels with minimum possible systematical error. The most important by now information on this nuclear parameter corresponds to the excitation energy region of levels which are not resolved by existing spectrometers of gamma-rays and nucleon products of nuclear reaction. Naturally, systematical error in determination of level density in this excitation energy region by means of any existing method will be maximal. There are no doubts that the main contribution in this error is carried by the hypotheses used for analysis of reactions under study and significant transfer coefficients of any their systematical errors onto errors of determination of level density and partial widths of emission of nuclear reaction products.

The last problem is stipulated by the fact that the transport coefficients of errors of any model set nuclear-physics parameters onto calculated cross-sections and amplitudes of spectra are always less than unity. And they are more than unity at solution of reversed task. In the worst case, determination of level density from reaction under study with uncertainty, for example, of some tens of percents requires one to measure reaction cross-sections and spectra of their products in realized by now methods with a precision not less than some percents or even better. As concerns concrete experiment, estimation of ordinary systematical errors of experimentally obtained level density usually is trivial task and problems of its determination are not considered here.

Selection of the most precise level density models from all their set [3] and maximally precise parameterization are impossible without the maximum reliable data on $\rho$. The obvious example – the value of energy of phase transition of a nucleus from superfluid to usual states in generalized model of superfluid nucleus. The authors of this model [4] have set energy of phase transition of a nucleus to superfluid state with the use of value of temperature of analogous transition of electron gas in superconducted state by the only reason – because of the lack of precise enough data on level density of different nuclei.

Experimental data of the methodically more precise way [5, 6] for determination of $\rho$ show that the adopted in [4] value of this energy, most probably, is overestimated by a factor of $\approx 2$. Or – phase transition of nucleus from superfluid to usual states occurs at successive breaking of Cooper pairs after increase in excitation energy by more than one nucleon pairing energy [7]. In this case, as and in the other known experimental methods, realistic estimation of systematical error of $\rho$ stipulated by the use of concrete model ideas on dependence of correlation function $\Delta$ of nucleon pair on energy at analysis of only experimental data cannot be performed without additional experimental information.

So, as concerns the problem of reliable determination of level density from the spectra of the nuclear reaction products, the biggest and unknown systematical error is, most probably, stipulated by the use of hypothesis of independence of interaction cross-section of the nucleus excited up to energy $U$ with reaction product at its energy $E_n$.

Zero hypothesis of independence of cross-sections on $U$ for this case was suggested by Bohr and Mottelson [8] for nucleon reaction products and by Axel and Brink [9, 10] for gamma-quanta. Both hypotheses are used by many experimentalists up to now as immutable truth. Although experimental possibilities for test of hypothesis [9, 10] were already found. It should be noted that the theory created apparatus for calculation of emission probability of nuclear reaction products which accounts for change in nuclear structure and for the case of arbitrary excitation energy of remainder nucleus see, for example, [11].

# 2 Modern possibilities for test of the used hypotheses

Most probably, direct experiment for test of hypotheses [8, 9, 10] cannot be performed. And corresponding data can be obtained only from measurement of some nuclear reaction functional for the all spectrum of energy values of registered product at obligatory fixation of excitation energy of remainder nucleus. For the first time this possibility was realized in [6]. There were determined the total and cascade populations $P$ of approximately 100 individual excited levels up to their excitation energy $U \approx 0.5B_n$ or some higher for about 20 nuclei. The pointed out ratio between the region of determined level populations and neutron binding energies $B_n$ is approximately fulfilled for nuclei with any parity of neutrons and protons.

The shape of functional dependence $P_i = f(U)$ for level $i$ for arbitrary nucleus is determined as sum of products of populations $P_\lambda$ of higher-lying levels $\lambda$ by ratios of partial width of given gamma-transition to the total radiative width of decaying level $\lambda$. Unfortunately, it is impossible to obtain by this method direct data on partial widths of any gamma-transitions for all the diapason $U \approx B_n$. Nevertheless, it was impossible to reproduce experimental data on cascade population in the framework of the Axel-Brink hypothesis. Moreover, the data on approximation [7, 12] of the experimental level density by Strutinsky model [13] (in the simplest variant with the use of constant value of coefficient of collective enhancement of level density [3]) allow one qualitatively to connect this discrepancy with significant increase of radiative strength functions $k = f/A^{2/3} = \Gamma/(E_\gamma^3 D A^{2/3})$ of both primary and secondary gamma-transitions to the levels with large phonon components of their wave functions in nucleus with mass $A$. This statement concerns arbitrary energy $E_\gamma$ and any spacing $D$ between decaying states.

The same conclusion can be done and from the main theses of quasi-particle-phonon model of nucleus.

Taking into account that the matrix elements of both gamma-transitions and neutron emission, for example, are determined [14] by components of wave functions of both initial and final levels, the obtained result calls doubts and of hypothesis [8] on independence of partial widths of emission of nucleon products of nuclear reactions on excitation energy of final levels. This assumption refers, by analogy with gamma-quanta, in the first turn to nuclear levels $U < 0.5B_n$. Practically – below the breaking threshold of the second Cooper pair of nucleons in even-even and even-odd nuclei. Hence, there are serious grounds in necessity to test the hypothesis [8].

## 3 Possible ways to test Bohr-Mottelson hypothesis

According to [8], the amplitude $N(E_n)$ of the measured, for example, in $(p, n)$ spectrum for $U > 0$ is determined by equation

$$N(E_n) = const\ \rho(U) E_n \sigma(E_n, U) \tag{1}$$

for total level density $\rho(U)$ and cross-section of excitation of nucleus-product $\sigma(E_n, U)$ by neutron with energy $E_n$. This equation in variant

$$N(E_n) = const\ \rho(U) E_n \sigma(E_n, U = 0) \tag{2}$$

for calculated within nuclear optical model cross-section $\sigma(E_n, U = 0)$ (penetration coefficients of nuclear surface $T$) is used up to now for determination of $\rho(U)$ from spectra of nucleon products of nuclear reactions [15, 16, 17].

Development of model independent method [5, 6] for determination of level density from intensities of two-step cascades and obtained with its help level densities allow one to test hypothesis [8] due to obvious possibility:

$$\sigma(E_n, U) \propto N(E_n)/(\rho(U)E_n) \tag{3}$$

and estimate degree of violation of condition $\sigma(E_n, U) = \sigma(E_n, U = 0)$. Selection of parameters of optical model for practical determination of level density can be ambiguous [16] and, consequently, subjective; there are no nuclei where simultaneously are determined level density from two-step gamma-cascades and spectra of evaporated neutrons. Besides, the sources of systematical errors were revealed and rejected only partially even in the more precise variant of level density determination [6]. Therefore, possible change of relative energy dependence of $\sigma(E_n, U)$ at increase of $U$ was preliminary estimated by means of relation (3) for two variants of the total level density in $^{181}$W. There are Fermi-gas model with "backshift" in variant of parameterization [18] and the simplest extrapolation of approximation parameters of level density of even-odd isotopes $^{183,185,187}$W [7, 12] onto $^{181}$W. Parameters $\rho$ and $k$ of cascade gamma-decay of tungsten isotopes were determined with the highest up to now accuracy and tested [19] and in calculation of the total spectrum of gamma-transitions following thermal neutron capture in natural element. The use of such extrapolation additionally decreases possible influence of structure of decaying compound state [19] on level density and radiative strength functions determined in concrete isotope.

The determined from (3) ratio $R = \sigma(E_n, U)^{EXP}/\sigma(E_n, U = 0)^{OM}$ is shown in Fig. 1 for spectra of evaporated neutrons experimentally measured in [20]. Cross-section $\sigma(E_n, U)^{EXP}$ of interaction of neutrons with nucleus $^{181}$W for excitation energy $U$ (completely reproducing data [20] at adopted here level density) can be found from the $R$ values for any calculated within optical model parameters $\sigma(E_n, U = 0)^{OM}$ (reproducing total level density [18]) or [4]. Determination of this ratio was performed without separation of spectra [20] onto "statistical" and "non-equilibrium" parts: this circumstance cannot bring principal changes in the conclusion. The ratios $R$ obtained for spectra with proton energy 6 to 10 MeV practically merge with one other in Fig. 1 in the region of overlapping excitation energies $U$.

The total level densities used in analysis are shown in Fig. 2. Parameters of approximating function for curve 2 and $^{183,185,187}$W are listed in Table. They provides for coincidence with curve 1 ($a = 17.61$ MeV$^{-1}$ and $\delta = -0.49$ MeV) in region $U \approx B_n$ and for low excitation energy of $^{181}$W. Corresponding parameters provide for practically equal discrepancy between level densities for two models of $\rho$ used for all even-odd tungsten isotopes.

Figure 3 represents relative values of sums of strength functions of the primary E1- and M1-transitions following depopulation of compound state obtained in [6]. Approximation of these and analogous data for the other nuclei [19] and its interpretation show that the strength functions can strongly depend on structure of decaying compound state $\lambda$ and low-lying levels $i$ (the ratios and values of quasi-particle and phonon components in their wave-functions [14]). Difference in form of the strength functions for $^{183,185,187}$W has so probable, but not verified experimentally explanation. In spite of this, the data presented in Fig. 3 permit one to assume the presence of common mechanism of increase in cross-sections of interaction of both gamma-quanta and neutrons (in given case) for levels in region of step-like structure near $U \sim 3$ MeV. At least – for the portion of decaying levels $\lambda$ with enhanced contribution of phonon components in partial width.

## 4 Discussion of results

So, from any experimental evaporation spectra one can obtain different of principle level density at respectively set cross-sections of interaction of reaction product with excited nucleus. The reliable and independently obtained level density makes it possible to determine cross-sections of nucleon interaction with excited nucleus and, probably, to derive information on on parameters of correlation function of Cooper pairs in heated nucleus. In this case, maximal increase in cross-section interaction of reaction product with remainder nucleus corresponds to region of the less level density. Localization of the effect in narrow energy region of nucleus excitation does not allow one even in principle to calculate change in cross-sections owing to difference in nuclear structure at arbitrary value of $U$. This conclusion concerns only calculation of $\sigma(E_n, U = 0)$ within optical mode of nucleus.

Estimation of maximum possible ordinary error in determination of $\rho$ from the two-step cascade intensities [21] (maximum error at change in the total intensity by 50% distorts the desired level density by maximum factor of 2) indicates potential possibility to determine $\sigma(E_n, U)^{EXP}$ with the same maximum error. At present, this accuracy would be enough in order to get reliable information on of interaction cross sections of nucleon with excited nucleus (but only at absence of other significant systematical errors).

Unfortunately, at present there is no possibility to get experimental information on:

(a) the function $k(E_\gamma, U)$ for arbitrary multipolarities of gamma-quanta, values of $E_\gamma$ and energies of excited by them levels above $U \approx 0.5B_n$;

(b) both presence/lack of dependence of the secondary gamma-transition widths on way of excitation of decaying level (for example, by evaporation nucleon, primary gamma-transition or cascade of gamma-quanta) and correctness of other model ideas of a nucleus.

Situation is complicated owing to lack of suitable for parameterization in experiment modern model of gamma-decay which directly accounting for coexistence and interaction of Fermi-Bose systems for any excitation energy.

Indeterminacy of these and other potentially possible errors of model notions and stipulated by them systematical uncertainties does not allow one to make unambiguous conclusions on size of region and magnitude of discrepancy between real cross-sections $\sigma(E_n, U)$ and those calculated within optical model of nucleus. Besides, this does not permit one to get, for example, information on degree of decrease of coefficient of vibration enhancement of level density at increase of $U$. I. e., to determine shape of energy dependence of correlation function of two nucleons $\Delta(U)$ in heated nucleus.

Development of independent method [22] for determination of level density and radiative strength functions from spectra of individual gamma-transitions of reaction $(\overline{n},\gamma)$ and its application [23, 24, 25] for compound nuclei $^{146}$Nd, $^{156,157,159}$Gd, $^{172,174}$Yb, $^{182}$Ta, $^{184}$W, $^{191}$Os, $^{231,233}$Th, $^{237,239}$U, $^{240}$Pu confirmed the presence of step-like structure in level density [5, 6] and, moreover, allowed one to make conclusion on rather essential overestimation of level density derived from the two-step gamma-cascade transitions. I. e., one can expect that the real cross sections of interaction of nucleons and gamma-quanta with excited nucleus noticeably exceed he value presented in Fig. 1.

# 5 Potential possibilities of experiment

So, the experimental methods used up to now cannot provide for precision of determination of level density which is required for practical search for dynamics of nuclear phase transition superfluid – usual state of nucleus.

The main sources of systematical error remain both the use the hypotheses not tested in experiment (first of all, hypothesis of independence of cross section of interaction of nuclear reaction product with excited nucleus on its excitation energy) and underestimation of systematical uncertainties in determination of nuclear parameters from spectra of products of one-step [15, 16, 17] nuclear reactions.

Solution of this problem requires one to develop new methods and to perform new experiments. Creation of the spectrometer of cascade gamma-quanta which can register cascades from three gamma-quanta with good efficiency [26] and following correct analysis will allow one, at least, in perspective to enlarge a bulk of high-quality and convenient for study of gamma-decay process within method [5, 6] information. First of all, there the data on dependence on strength functions of gamma-quanta of equal energy on nuclear excitation energy. This will permit one to decrease systematical error of the level density determination within method [6] to minimally possible value - some tens percents. But, this perspective does not exclude necessity to perform independent experiments within sufficiently different methods. This can be the experiment in which are registered cascades of type "nucleon product" and "gamma-quantum" ending at several low-lying final levels of nucleus with the use of the method of summation of amplitudes of coinciding pulses from detectors of charged particles and gamma-quanta. Such experiment can be performed for spherical, for example, nucleus by means of high-efficiency scintillation detectors of moderate resolution. In deformed nuclei, however, it is necessary to use multi-detector systems on basis of semiconductor detectors.

Principle possibility of this experiment and its expected high information efficiency result from comparison of intensity $I_{\gamma\gamma}$ of cascades from two successive gamma-transitions in function of their primary transition energy $E_1$:

$$I_{\gamma\gamma}(E_1) = \sum_{\lambda,f}\sum_{i}\frac{\Gamma_{\lambda i}}{\Gamma_{\lambda}}\frac{\Gamma_{if}}{\Gamma_{i}} = \sum_{\lambda,f}\frac{\Gamma_{\lambda i}}{<\Gamma_{\lambda i}> m_{\lambda i}}n_{\lambda i}\frac{\Gamma_{if}}{<\Gamma_{if}> m_{if}} \tag{4}$$

and intensity $I_{N\gamma}$ of cascades with any possible primary nucleon reaction product:

$$I_{N\gamma}(E_1) = \sum_{\lambda,f}\sum_{i}\frac{T_{\lambda i}}{T_\lambda}\frac{\Gamma_{if}}{\Gamma_i} = \sum_{\lambda,f}\frac{T_{\lambda i}}{< T_{\lambda i} > m_{\lambda i}} n_{\lambda i}\frac{\Gamma_{if}}{< \Gamma_{if} > m_{if}}. \tag{5}$$

Here is assumed that the cascades proceed between group of initial levels $\lambda$, arbitrary number ($n$) of intermediate $i$ and several final levels $f$. The spins of all levels are determined by experimental conditions and selection rules of level spins and orbital momentums of reaction products. In these equations, the partial (2 indexes) and total (1 index) widths $\Gamma$ (of penetrability $T = 2\pi\Gamma/D_\lambda = 2\pi\Gamma\rho_\lambda^{-1}$) belong to emission on reaction product at fixed step of cascade. The numbers of excited levels $n = \rho\Delta E$ (or $m$) belong to different intervals $\Delta E$ of distributions under analysis. Both systems have infinite number of possible values of parameters determined them: partial widths of decay of levels $\lambda$ $i$ and level densities.

Transition from differential cross sections used in [15, 16, 17] to ratio of widths in (5) calls no difficulty.

# 6 Potential possibility and practical conditions of extraction of maximal information from systems of degenerated nonlinear equations

The final goal of any experiment is determination of the most probable interval of the desired parameters and minimization of its width. In this approach appears possibility to get useful information and in case of degenerated system of equations connecting changeable function with its parameters under study. This can be done if the systems of these equations describe closed surface in space of any number of parameters. Therefore, one can determine interval of possible values of any number $N > M$ of parameters for any system of $M$ nonlinear equations. The interval of possible values of parameters is minimum at minimum volume restricted by surface. The problem to solved in this case is a necessity to include in analysis maximum quantity of additional information in form of additional functional connections of parameters with available for determination values and fixation of their minimum (maximum) value.

In favorable cases, the connection between partial widths of system (4) at the first and second steps can be determined experimentally. Then system of equations (4) is successfully approximated by level density and partial widths from final and the least interval of their values. Its real width for the cascades from two gamma-quanta at very small statistical errors of determination of $I_{\gamma\gamma}(E_1)$ can be equal to some tens percents. It is necessary for this additionally to fix also level density at the lower and highest values of excitation energy, ratios between partial widths of gamma-transitions with different multipolarity at some enegies of gamma-transitions, total radiative widths of decaying levels $\lambda$, spins and parities of three cascade levels an so on.

Mathematically, systems of equations (4) and (5) are equivalent and conclusions made above are true for both (4) and (5). But, there are principle differences which bring to change in width of interval of possible values of the desired parameters in case (5) with respect to (4). This is stipulated by impossibility of unambiguous experimental determination of the measured intensity in function on reaction product at the first step for two gamma-quanta and absolutely unambiguous – for the first nucleon. Besides, it is caused by different numbers of parameters under determination.

Registration of the spectrum of nucleon product in wide interval of its energy will give experimental value of product of unknown for level $i$ value $T$ by number of excited levels $n_i$ in any energy interval $E_n$. I. e., – multiplier $\sum_i (T_{\lambda i}/T_\lambda) n_i$. Experimentally determined for energy interval $\Delta E$ intensity $I_{N\gamma}$ additionally contains in (5) unknown ratio of partial and total radiative widths of the secondary cascade transitions averaged over spins levels $i$.

The total spectrum of intensity $I_N = \sum_i (T_{\lambda i}/T_\lambda) n_i$ in expression (5) must be registered not only in coincidences but also independently on gamma-quanta; its portion entering in (5) can be estimated from ratio of level density in given spin window to total density of all levels.

Application of the algorithm used in method of analysis of two-step cascade intensities for search of random functions with equal precision reproducing experimental intensities (variant of Monte-Carlo method) will permit one to determine the regions of possible values of level density and radiative strength functions of the secondary gamma-transitions of cascades and for case (5). And then by use of the found level density – to determine $T$ with guarantied methodically reliability.

In Fig. 4 are shown intensities $I_{N\gamma}(E_n)$ (for proton energy 8 MeV) calculated with use of given in [20] experimental spectrum of evaporation neutrons and different combinations of functional dependences of level density and radiative strength functions on energies of excitation and gamma-transition. All variants of calculation assume registration of cascades to 5 final levels of $^{181}$W with maximum energy 457 keV with their spin values - to 9/2 [28].

The spectra of random functions $\rho = \phi(U)$ and $k = \psi(E_\gamma)$ for two expected level densities and radiative strength functions of $E1$-transitions calculated within models [9, 10] with $k(M1)$=const are presented in figures 5 and 6. Each pair of these functions reproduces curve 1 or 2 in Fig. 4 practically with zero value of $\chi^2$.

They were determined with use of the additional data [29] and [3] on: (a) the density of neutron resonances and low-lying levels of unucleus under consideration; (b) the total radiative width $\Gamma = 70$ meV of gamma-decay for levels with $J^\pi = 1/2^+$ at excitation energy $U = 6.65$ MeV; (c) the ratios $k(M1)/k(E1)$ determined from the experiment and (d) the absolute value $k(E1) = 1.4 \times 10^{-9}$ MeV$^{-3}$.

The use of this information permits one to obtain the least width of interval of dispersion of random functions $\rho = \phi(U)$ and $k = \psi(E_\gamma)$. Significant increase in fluctuations of level density in region $U = 6$ MeV has technical character and is stipulated only by high registration threshold of evaporation neutron $E_n = 1$ MeV in [20].

It is seen from the data of Fig. 4 that the suggested experiment has maximal sensitivity to level density. As it follows from figures 5 and 6, the mean value of random functions $\rho = \phi(U)$ and $k = \psi(E_\gamma)$ for any values of $U$ and $k$ can be considered as their most probable value.

This result confirms possibility to obtain maximum reliable at present information on level density and partial widths of nucleon and gamma-quantum emission up to the excitation energy of any nucleus not less than $\sim 5-10$ MeV. And, as a consequence, to obtain inaccessible up to now information on cross sections of interaction of gamma-quanta, nucleons and light nuclei with excited nucleus at the least hypotheses of these nuclear parameters. Moreover, the cross-section derived from comparison of the measured intensity of nucleon product with obtained level density is always determined unambiguously.

The result of the analysis can contain more or less error in case if real $\rho$ and $k$ values strongly deviate from the most probable (here – the averaged) value.

# 7 Conclusion

The comparison between the one-step [15, 16, 17] and two-step [5, 6] experiments and analysis of possible reasons of the observed discrepancy in results of the $\rho$ determination demonstrated a necessity to use in the first case for determination of level density only experimental cross sections of interaction of reaction product with the excited reminded nucleus. Or calculate these cross sections within modern nuclear models which take into account influence of structure of excited nucleus on cross sections of interaction of nucleons with it with well precision. The precision in determination of level density in this case is unambiguously determined by error in theoretical calculation of cross sections.

The analysis of conditions for extraction of level densities from cascades "neutron and gamma-quantum" was performed with using different model notions of level density and radiative widths of dipole cascade transitions and experimental evaporation spectra of the $^{181}\mathrm{Ta}(p,n)^{181}\mathrm{W}$ reaction. It allowed one to estimate expected interval of the $\rho$ and $k$ values in practically possible experiment. Besides, it has demonstrated a possibility of systematical determination of cross-sections of interaction of nucleons (light nuclei) with excited nucleus together with the $\rho$ and $k$ values with rather high extent of reliability.

It is not excluded that the only possibility for experimental determination of level density with precision of $\delta\rho/\rho \sim 50\%$ and higher can be only the experimental data derived from analysis of many-step reactions with the emission at the first step of nucleons (light nuclei) or gamma-quanta.

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*Table 1.*
The adopted ($^{181}$W) and approximated ($^{183,185,187}$W) thresholds $U_n$ (MeV) of appearance of $n$-quasiparticle excitations and coefficient of collective enhancement $K_{\rm coll}$ in model [13].

| Mass | $g$, MeV$^{-1}$ | $K_{\rm coll}$ | $U_3$ | $U_5$ | $U_7$ | $U_9$ |
|---|---|---|---|---|---|---|
| 181 | 10.7 | 15 | -1.50 | 2.20 | 3.80 | 6.10 |
| 183 | 10.2 | 16.3 | -1.49 | 2.58 | 4.56 | |
| 185 | 10.3 | 12.2 | -1.87 | 3.19 | 3.97 | |
| 187 | 11.3 | 8.4 | -1.27 | 2.81 | 3.57 | |

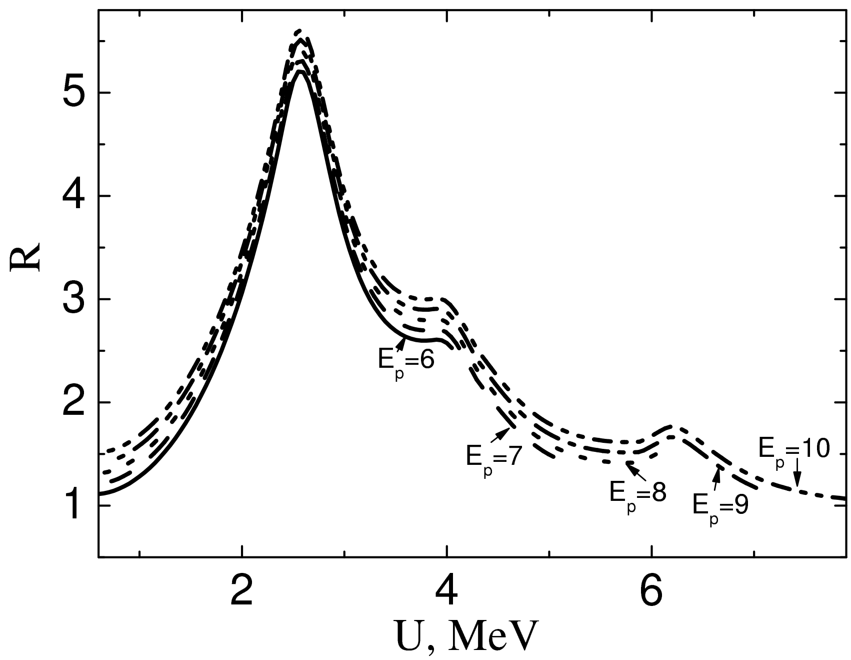



**Fig. 1.** The ratio of the cross-section $\sigma(E_n, U)^{EXP}$, which reproduces the experimental data [20] at the step-like level density (curve 2 in Fig. 2) to analogous cross-section, in combination with the Fermi-gas level density which reproduces the same spectra. The curves are noted by proton energies and shifted upwards by 0.1 with respect to each other.

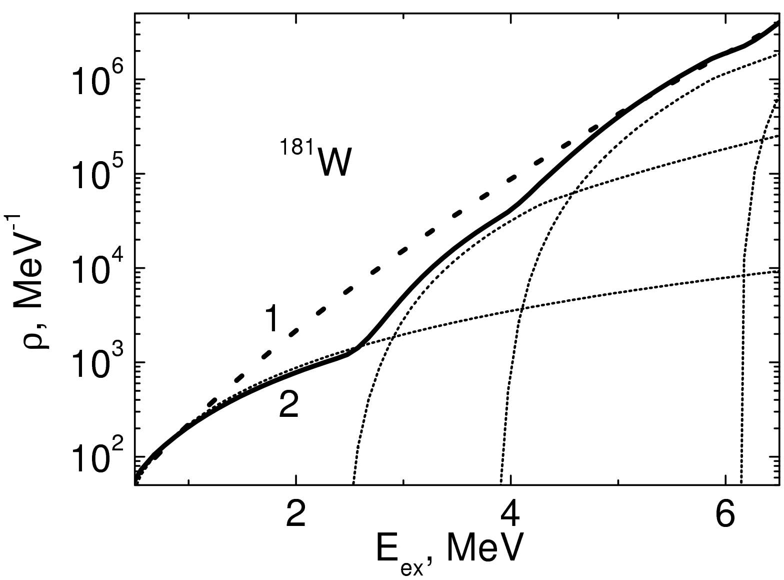



**Fig. 2.** Curve 1 – the total level density of the Fermi-gas model with the back-shift [18] with the parameters $a = 17.61$ MeV$^{-1}$ and $\delta = -0.49$ MeV. Thin curves – the partial densities of three-, five-, seven- and nine-quasiparticle levels. Curve 2 represents their sum.

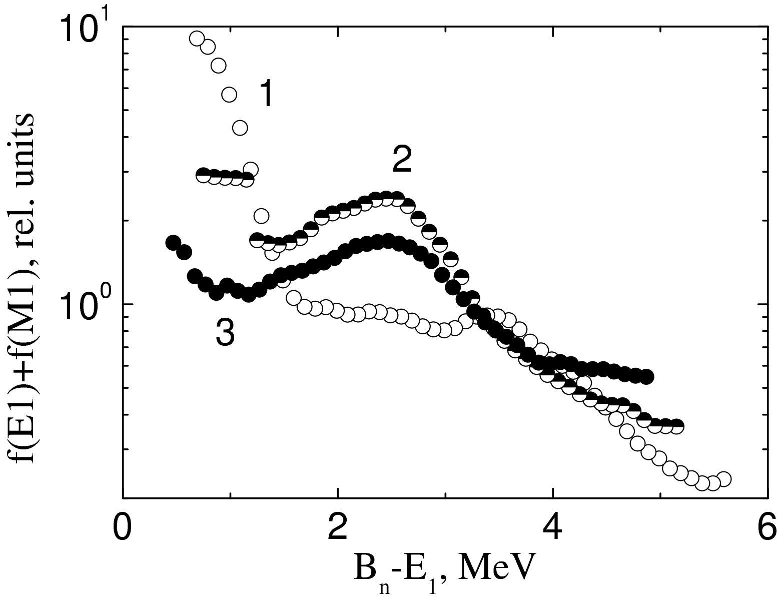



**Fig. 3.** Curves 1, 2 and 3 – relative values of the radiative strength function sums of the primary gamma-transitions following decay of compound nuclei $^{183,185,187}$W, respectively, exciting levels with energy $U = B_n - E_1$.

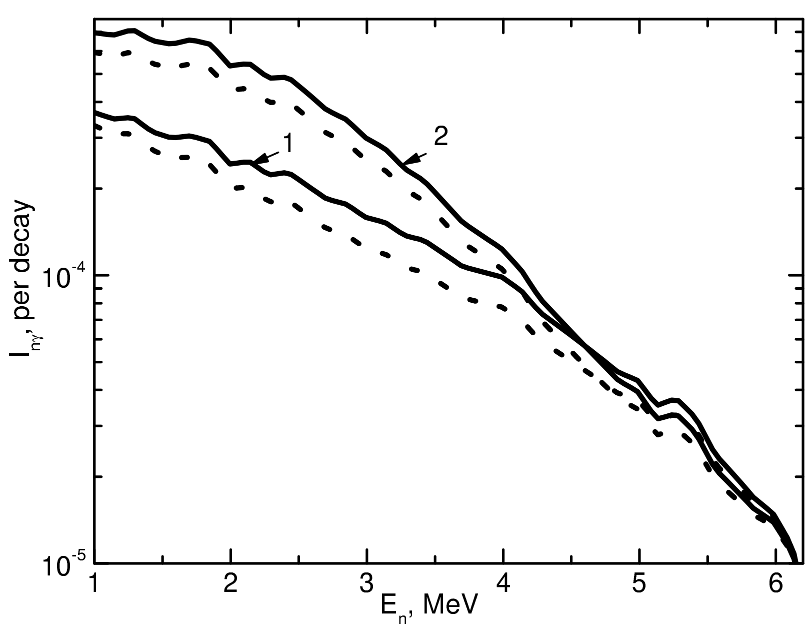
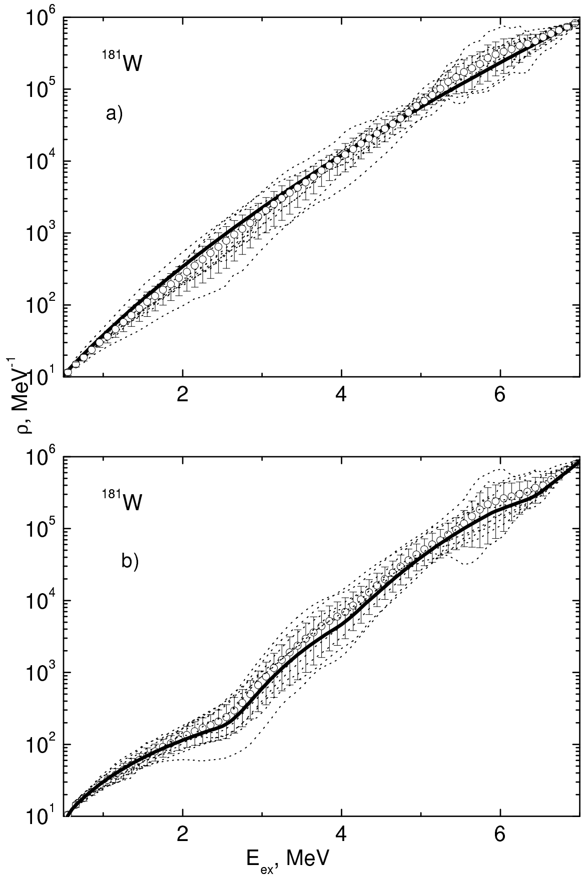



**Fig. 4.** The calculated intensity of the cascade "neutron and gamma-quantum" in $^{181}$W for proton energy 8 MeV. The spectrum from [20] was re-normalized to 1, the solid curve 1 was obtained in calculation (5) within models [18] and [9, 10]. Curve 2 – within models [13] and [9, 10]. The dotted curves – the same models of level density and model [27]. The value $k(M1)$ =const was used in all calculations.



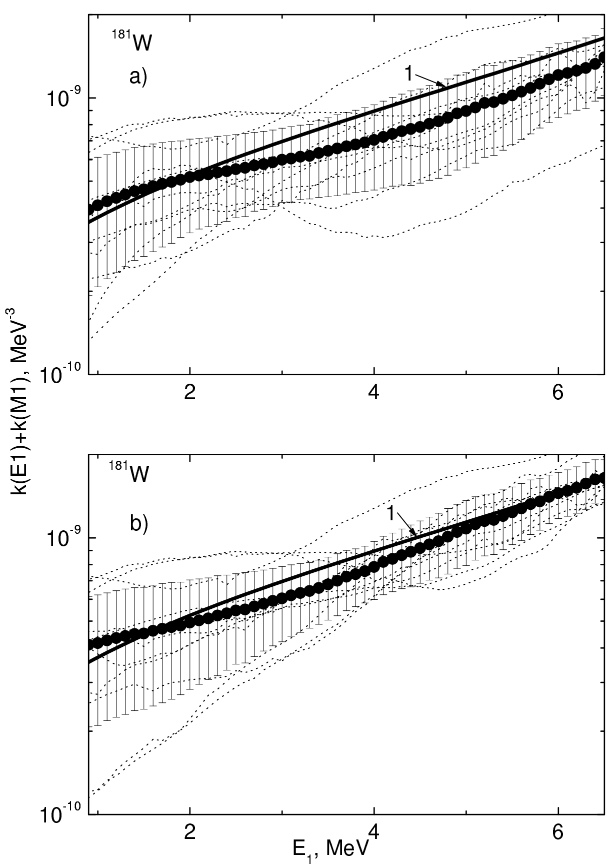




**Fig. 5.** The results of approximation of cascade intensities presented by curves 1 and 2 in Fig. 4. Solid curves – level density from [18] and [13], (a) and (b), respectively. The dotted curves – random functions $\rho = \phi(U)$. Points with errors – their averaged value with the mean square dispersion.

**Fig. 6.** The same, as in Fig. 5, for the determined from (5) sums $k(E1) + k(M1)$. Line 1 – model [9, 10] for $E1$-transitions in sum with $k(M1)$=const.