CALCULATION OF THE TOTAL GAMMA-SPECTRA OF THE FAST NEUTRONS CAPTURE IN THE ISOTOPES $^{117,119}$Sn FOR THE DIFFERENT PARAMETERS OF CASCADE GAMMA-DECAY

A.M. Sukhovoj, V.A. Khitrov

Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research, 141980, Dubna, Russia

The gamma-spectra were calculated for the set of different level densities and radiative strength functions. The sufficiently precise reproduction of the experiment is impossible without taking into account the influence of the process of the nucleons Cooper pairs breaking on any nuclei cascade gamma-decay parameters.

1 Introduction

The direct determination of density $\rho$ of excitation levels (number of levels of nucleus in the unit interval of excitation energy) for the larger part of stable and long-life radioactive target nuclei is impossible. This assertion relates also to the radiative strength functions

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

exciting their primary dipole electrical and magnetic gamma-transitions of level of nucleus decaying the excited in the nuclear reaction. Extraction of the parameters of nucleus in question in this situation can be executed by only their fitting to the optimum values, reproducing the experimental spectra and cross section with the minimum standard deviation measured in the nuclear reactions.

This inverse problem of mathematical analysis by its nature is principally ambiguous. Moreover, systems of equations, connecting the number of excited levels and probability of the emission of nuclear products are usually assigned within the framework of some ideas about the mechanism of nuclear reaction and factors determining the dynamics of the studied process.

Thus, for example, the description of the cascade gamma-decay of neutron resonance, is impossible at present without the introduction of some a priori ideas. In particular, within the framework of the ideas about this process following potential possibilities are not taken into consideration:

- the presence of the possible strong dependence of neutron widths $\Gamma_n$ on the structure of the wave function of resonances (and of the excessive error in determination of their density $D_{\lambda}^{-1}$ by the neutron time-of-flight method),

- the analogous dependence of the partial radiative widths of primary gamma-transitions $\Gamma_{\lambda i}$ on the structure of the level excited by them, evidently overstepping the limits of the expected Porter-Thomas fluctuations.

Potential possibility of existence of the enumerated effects and their significant influence on the process of cascade gamma-decay directly follows from the results [1] of model
approximation of the level density, extracted from the reaction \((n, 2\gamma)\) and the comparison [2,3] of the average values of the sums of radiative strength functions with their models [4,5] most often used in practice. Thus, the possible break of sequential Cooper pair [1] with the excitation energy in the region of the neutron-binding energy can change values of few quasi-particle components in the wave function and thus - change [6] values of \(\Gamma_n\). This possibility directly follows from the results, presented in [1]. Whether this possibility is realizable in principle, to what degree the process of fragmentation of nuclear states mixes up components of different types in the wave functions of the levels in the whole region \(E_{ex} \leq B_n\) and at the noticeably higher excitation energies - neither the experiment, nor the theory can answer this at the present.

In particular it is not possible to obtain the realistic estimation of the part of the unobservable levels, which according to the values \(J^\pi\) could be excited them as s-resonances. This problem is very essential, since the density of neutron resonances in practice in any experiment to determine this parameter for the excitation lower than \(B_n\) is used to standardize its relative values. As a consequence of the above mentioned facts, the measured experimentally in different procedures [2,3,7,8] level densities and the radiative strength functions of primary gamma-transitions can have an unknown systematic error, the value of which directly depends on a systematic error in the conventional values \(D_\lambda\) of the spacing between the neutron resonances. And the obtained ideas about these values and properties of nucleus can be erroneous to a greater or lesser extent. However, if we add the fundamental incompatibility of the data about the level density between the results of applying the procedures [7,8] on the one hand, and [2,3] on the other hand, than the need for a maximally possible verification of \(\rho\) and \(k\) determined from indirect experiments becomes obvious.

2 Possibilities and the specific character of the verification of the experimentally determined values of \(\rho\) and \(k\)

The verification of the indicated parameters of nucleus can be partially executed by the calculation of total gamma-spectra for different sets of \(\rho\) and \(k\) with their subsequent comparison with the experiment. This calculation was carried out by different authors repeatedly [9,10], but, as a rule, without taken into account of:

- the nonconformity of the model assigned ones and real values of \(\rho\) or \(k\) if to determine one of these values purely model presentations about another value are used;
- the specific character of the transfer of errors \(\delta \rho\) and \(\delta k\) to an error \(\delta S\) of the calculated spectrum;
- all aspects of the influence of the structure of the excited levels of nucleus on the found parameters \(\rho\) and \(k\).

All these problems become apparent to the full during the calculation of the gamma-ray spectra of the radiative capture of thermal neutrons, measured, for example, by Groshev [11], with the use of \(\rho\) and \(k\), determined from the gamma-ray intensities in the procedures.
The major part of experimental data on the total gamma-ray spectra of the capture not only of thermal but also fast neutrons was used to verify such data earlier [12].

The measurement [13] of total gamma-spectra in the isotopes $^{118,120}$Sn makes it possible to carry out the same analysis for the spherical nuclei from the region of minimum of neutron strength function for the s-neutrons. And to thus to test obtained and represented into [3] the values $\rho$ and $k$.

3 The comparison of calculation and experiment

With the comparison it is necessary to consider the specific character of the operation of the transfer of errors $\delta \rho$, $\delta k(E1)$ and $\delta k(M1)$ to an error in the calculated total gamma-spectrum: it is characterized by very low coefficients. (And, obviously, by very large in the opposite case.)

Consequently, calculated spectra, close ones in the quality of reproduction to the data of experiment can be obtained for the substantially being differed values $\rho$ and $k$. And, all the more, this is correct with the presence experimentally [2] of the established strong dependence of the process of cascade gamma-decay on the nuclear structure, as the minimum, for the excitation energies of $E_{ex} < 0.5B_n$.

Therefore the comparison of calculation and experiment should be conducted for the maximum collection of the diverse variants of functional dependences $\rho$ and $k$ is without fail on the line scale. It is most expedient also to perform the comparison of total gamma-spectra for the spectrum corresponding to the product of the gamma-quantum intensity on their energy. The condition $\sum I_\gamma E_\gamma = B_n$ ensures the maximally precise normalization intensities of the observed gamma-transitions in average and the presence of errors of different sign - for different values of gamma-quantum energies.

Reliable experimental data for $\rho$ and $k$ in the nucleus $^{120}$Sn for the range of the excitation energies of $E_{ex} \approx B_n$ are absent. Therefore is below for calculating the total gamma-spectrum in this nucleus of values $\rho$ and $k$ are converted from the results [3] by the appropriate scaling of these given for the nucleus $^{118}$Sn.

The level densities of both parities and spins 0, 1 and 2 for these compound nuclei are given in Fig. 1; the radiative strength functions of primary E1- and M1-transitions with the maximal coefficients [2] of an increase in the radiative strength functions of secondary transitions are given in Fig. 2 respectively. The calculated total gamma-spectra of the capture of fast neutrons in the $^{117,119}$Sn are compared with the experiment in Fig. 3 and 4 for few sets of the values of the level density and radiative strength functions. Corresponding calculation data for $^{118,120}$Sn are given in Fig. 3, 4.

These data are acquired as follows: the level density and radiative strength functions are extrapolated to the excitation energy $E_{ex} = B_n + 100$ keV. And then - they were used for calculating the total gamma-spectra for the spins of the decomposed initial levels of $J_\pi = 0^+, 1^+$ and for $J_\pi = 0^-, 1^-, 2^-$. The portion of their contribution to the resulting spectrum was determined by the fitting of the function of $S^{exp} = k_j S^{cal}(J_\pi)$. I.e., with the calculation of total gamma-spectra was considered capture only by s- and p -neutrons, and the portion of the captures of $k_j$ for each of the possible spins of compound- states was the free parameter. Obtained values are given in the table for the minimum $\chi^2$. Here one
should note, that the minimum $\chi^2$ with the use of standard model [4,5,14] can be achieved only for negative contribution of one of the spin states (in the table it substituted to the zero value). Taking into account great significance $\chi^2$ can be concluded, that procedure [2] determination $\rho$ and $k$ reproduces experimental data on the total gamma-spectra is more accurately, than model presentations of the type [4,5,14]. The existing deviations totally can be connected only with the inevitable errors of experimental data for $\rho$ and $k$, the obtained from the two-step cascades of capture thermal neutrons into $^{117}$Sn. First of all - because of the absence of data according to the radiative strength functions of primary E1-transitions to the levels of these nuclei with the excitation energy less than 2-3 MeV. Or - because of the presence of the strong dependence of the radiative strength functions of primary transitions from the structure of the decayed compound-states not only with the small ($E_{ex} < 0.5B_n$) excitation energies, but also for $0.5B_n < E_{ex} \leq B_n$.

Table. The most probable portion $k_J$ of experimental spectrum, corresponding to the decay of compound-state with the spin of $J^\pi$ with the use of experimental data [2] and model presentations [4] and [14] for the strength functions and the level density.

|       | $^{118}$Sn |       | $^{120}$Sn |
|-------|------------|-------|------------|
| $J^\pi$ |  [4,14]   |   [2]  |  [4,14]    |   [2]   |
| 0$^+$  | 0.16(16)   | 0.00(30) | 0.21(86)   | 0.18(21) |
| 1$^+$  | 0.18(34)   | 0.39(33) | 0.00(21)   | 0.29(16) |
| 0$^-$  | 0.21(54)   | 0.00(30) | 0.12(98)   | 0.28(16) |
| 1$^-$  | 0.21(75)   | 0.01(30) | 0.30(18)   | 0.07(6)  |
| 2$^-$  | 0.16(91)   | 0.53(83) | 0.15(17)   | 0.04(6)  |
| sum   | 0.92       | 0.93   | 0.78       | 0.86     |

The results of the comparison of the spectra, calculated for different functional dependencies of level density and of the strength functions of dipole gamma-transitions with the experiment, quite unambiguously lead to the conclusion, fully coinciding with those obtained earlier:

- “smooth” function $\rho = f(E_{ex})$ reproduces the total gamma-spectrum of the thermal neutron capture noticeably worse, than the stepped functional dependencies obtained in [2,3];

- Is hence automatic (because of the strong correlation $\rho$ and $k$) follows the impossibility of the precise description of the experimental values of $k$ by model presentations of the type [4,5].

In particular, taking into account the influence of the structure of the excited levels on a change in the form of the energy dependence of radiative strength functions most likely should be carried out up to the neutron binding energy. One must not exclude the possibility that the radiative and neutron strength functions also depend on the structure of neutron resonances at the excitation energies larger, than $B_n$. 
4 Conclusion

The comparison of the total gamma-spectra for different functional dependencies of \( \rho \) and \( k(E1) + k(M1) \) both on the excitation energy of nucleus and on the energies corresponding to the primary and secondary gamma-transitions for the thermal neutrons capture in \(^{117,119}\text{Sn}\) with the experimental data was carried out. The comparison showed that model predictions of the non-interacting Fermi gas level density in these nuclei give worse correspondence, than the level density from the procedures [2,3]. This conclusion corresponded to the one obtained earlier [12].

Large transfer coefficients of the errors \( \delta S \) of total gamma-spectra to the errors \( \delta \rho \) and \( \delta(k(E1) + k(M1)) \) directly follow from the comparison of the data in Figs. 1, 2 and 3, 4. This circumstance confirms the conclusion [1], that the measurement of such spectra, for example in the procedure [8], requires accuracy on \( \sim 2 \) orders larger, than in the procedure [2,3]. And it limits the possibilities of the independent checking of different sets of \( \rho \) and \( k \), both of model determined ones and of experimentally obtained ones. The use of total gamma-spectra for their testing necessary requires the comparison of different variants of such data.

And even total reproduction of the experimental total gamma-spectrum by calculation with a certain set of \( \rho \) and \( k \) is not the proof of the correspondence of these values to the real parameters of nucleus. However, explicit nonconformity is a quite single-valued proof of the presence of larger or smaller systematic deviation for them with the experimental one.
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Fig. 1. The level densities of both parities and spins 0, 1 and 2 for compound nuclei $^{118,120}$Sn. Line 1 presented the used in calculations values of the level density with spins $J=(0-2)^+$, line 2 - the same for negative parity only. The dash line represents predictions of the model [14].

Fig. 2. Solid lines presented the radiative strength functions of primary E1- and M1-transitions (multiplicated on $10^9$). Line 1- maximum increasing of the radiative strength functions of secondary transitions to the levels with the energy of $E_{ex} = B_n - E_1$. Line 2 and 3 represent predictions of the model [5] and [4] in the sum with $k(M1)$=const. For both models is used the ratio $k(M1)/k(E1) = 0.2$ for of $E_1 = 6.5$ MeV.
Fig. 3. The experimental (points+line) total spectra of $\gamma$-radiation following fast neutron capture for the $^{117,119}$Sn targets. Lines 1 represent results of calculation using data of Ref. [2], line 2 - from [4,14], corresponding.

Fig. 4. The same, as on Fig. 3. Lines 1 represent results of calculation using data of Ref. [3], lines 2 - from [5,14], corresponding.