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Photoneutron Reactions in the Range of Giant Dipole Resonance[1]

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Abstract—The well-known significant systematic disagreements between data on partial photoneutron reaction cross sections obtained in experiments using quasimonoenergetic annihilation photons and bremsstrahlung were investigated using objective physical criteria of data reliability. It was shown that many data are not reliable because of significant systematic uncertainties of the photoneutron multiplicity sorting methods used. The experimental–theoretical method for evaluation of reliable partial reaction cross sections was proposed and many new data were obtained.

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INTRODUCTION

Cross sections of partial photoneutron reactions with different numbers of outgoing particles, primarily (γ, 1*n*), (γ, 2*n*), and (γ, 3*n*), are widely used in fundamental nuclear physics research such as studies of the Giant Dipole Resonance (GDR) excitation and decay mechanisms (configurational and isospin splitting, competition between statistical and direct processes in GDR decay channels, sum rule exhaustion, etc., [1]) and many applications including astrophysical [2, 3], medical, geological, technological problems, ultra–relativistic heavy–ion colliders beam luminosity monitoring [4], etc. Photonuclear reaction data are included into various reviews, Atlases [5, 6] and databases [7–9].

Many data on total and partial photoneutron reaction cross sections were obtained in experiments of different types, primarily the following:

—experiments using bremsstrahlung with continuous spectrum of photons; the majority of data was obtained in Russia (Moscow and Saratov State Universities, Institute of Nuclear Research of Academy of Science), Australia (Melbourne University) and some others;

—experiments using quasimonoenergetic photons obtained by the annihilation in flight of positrons; the majority of data was obtained at Livermore (USA) and Saclay (France) and some others.

Because the bremsstrahlung spectrum is continuous two steps are needed for obtaining the reaction cross section:

(i) The first step is the measurement [1] of the reaction yield $Y(E_m)$

$$Y(E_m) = \alpha \int_{E_{th}}^{E_m} W(E_m, E)\sigma(E)dE, \qquad (1)$$

where the cross section $\sigma(E)$ of the reaction with threshold E_{th} dependent on photon energy E is folded with photon spectrum $W(E_m, E)$ with end–point energy E_m;

(ii) The second step is unfolding of reaction cross section σ from the yield Y using one of well–known specially developed mathematical methods.

Experiments using quasimonoenergetic annihilation photons [5, 10] are based on the process of producing by fast positrons annihilation photons with energy $E_\gamma = E_{e^+} + 0.511$ MeV. Those are accompanied by positron bremsstrahlung and therefore three steps are needed for obtaining the reaction cross section:

(i) The first step is the measurement of the yield $Y_{e^+}(E_m, E)$ of reaction induced by photons from e^+ both annihilation and bremsstrahlung;

(ii) The second step is the measurement of the yield $Y_{e^-}(E_m, E)$ of reaction induced by photons from e^- bremsstrahlung;

(iii) The third step is the subtraction procedure

$$Y_{e^+}(E_m, E) - Y_{e^-}(E_m, E) = Y(E_m, E) \approx \sigma(E). \qquad (2)$$

The result is interpreted as "the reaction cross section measured directly".

Because of using noticeably different methods significant systematic disagreements between the results of various experiments exist. On the base of complete

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systematic of integrated cross sections obtained for more than 500 data sets of neutron yield reaction

$$\sigma(\gamma, \mathrm{Sn}) = \sigma(\gamma, 1n) + 2\sigma(\gamma, 2n) + 3\sigma(\gamma, 3n) + \ldots \quad (3)$$

it was shown [11, 12] that systematically Livermore data are lower than others: average integrated cross section ratio $R^{\mathrm{int}}_{\mathrm{syst}} = R^{\mathrm{int}}_{\mathrm{syst\text{-}varios}} \big/ R^{\mathrm{int}}_{\mathrm{syst\text{-}Livermore}}$ is about 1.12.

1. THE PROBLEM OF PARTIAL PHOTONUCLEAR REACTION DATA RELIABILITY

Two types experiments described above are quite different concern the way of obtaining partial reaction cross sections. Energy thresholds of the mentioned partial reactions are relatively close. Thus, there are ranges of the incident photon energy where there are a competitions of two or three open reaction channels.

Using bremsstrahlung at first the neutron yield reaction cross section σ(γ, Sn) is obtained by solving of inverse task (1). After that total photoneutron reaction cross section

$$\sigma(\gamma, \mathrm{tot}) = \sigma(\gamma, 1n) + \sigma(\gamma, 2n) + \sigma(\gamma, 3n) + \ldots \quad (4)$$

is obtained using special corrections for σ(γ, Sn) based on statistical theory. From σ(γ, Sn) and σ(γ, tot) cross sections for different partial reactions (γ, 1*n*), (γ, 2*n*), (γ, 3*n*), etc. are obtained using correspondent subtraction procedures. For example, at energies below the threshold *B*3*n* of the reaction (γ, 3*n*)

$$\sigma(\gamma, 2n) = \sigma(\gamma, \mathrm{Sn}) - \sigma(\gamma, \mathrm{tot}). \quad (5)$$

Using quasimonoenergetic annihilation photons and the method of neutron multiplicity sorting it is possible to obtain at first directly cross sections for partial reactions (γ, 1*n*), (γ, 2*n*), (γ, 3*n*), etc. and after that total neutron (4) and neutron yield (3) reaction cross sections using correspondent summing.

Most of such partial photoneutron reaction cross sections were obtained at Livermore (USA) and Saclay (France) [5, 10]. Both laboratories to identify reactions (γ, 1*n*), (γ, 2*n*) and (γ, 3*n*) employed the same method for neutron multiplicity sorting based on the assumption that spectra of neutrons from those reactions are quite different. Methods for neutron energy measuring used for its multiplicity determination differ significantly and therefore in many cases for the same nuclei σ(γ, 1*n*) are noticeably (up to 100%) larger at Saclay, but σ(γ, 2*n*) vice versa at Livermore [11–14]. From the systematics of integrated cross section ratios $R^{\mathrm{int}} = \sigma^{\mathrm{int}}_{\mathrm{Saclay}} \big/ \sigma^{\mathrm{int}}_{\mathrm{Livermore}}$ for 19 nuclei it was obtained [15, 16] that the average $\langle R^{\mathrm{int}}(1n)\rangle$ is about 1.08 but $\langle R^{\mathrm{int}}(2n)\rangle$ is about 0.83.

The possible reasons of those disagreements were investigated in details [11–14, 17]. It was shown that the differences between partial reaction cross sections originated from the procedures used to separate counts into 1*n* and 2*n* events—neutron multiplicity sorting. Unfortunately those investigations were not systematic and therefore the correspondent recommendations were contradictory. For example the Table 1 contains factors $F = \sigma^{\mathrm{int}}_{S} \big/ \sigma^{\mathrm{int}}_{S}$ proposed [17] for normalization of Saclay and Livermore (γ, 1n) reaction data. One can see that at the same time it is proposed to multiply Livermore data using *F* = 1.00–1.22 and multiply Saclay data using *F* = 0.80–0.93.

Table 1. Factor $F = \sigma^{\mathrm{int}}_{L} \big/ \sigma^{\mathrm{int}}_{S}$ [17] for normalization of Livermore and Saclay σ(γ, 1*n*) data

Nucleus	Laboratory	F
$^{\mathrm{nat}}$Rb, ^{89}Sr	Saclay	0.85 ± 0.03
^{89}Y	Saclay	0.82
	Livermore	1.0
^{90}Zr	Saclay	0.88
^{90,91,93}Zr	Livermore	1.0
^{93}Nb	Saclay	0.85 ± 0.03
^{94}Zr	Livermore	1.0
^{127}I,	Saclay	0.8
^{197}Au	Saclay	0.93
^{206,207,208}Pb	Livermore	1.22
^{208}Pb	Saclay	0.93
^{209}Bi	Livermore	1.22

In [13, 14] using the data of alternative activation method it was proposed that (γ, 1*n*) and (γ, 2*n*) reactions data differences arise from neutron multiplicity sorting—separation of counts into 1*n* and 2*n* events. That was shown that Saclay σ(γ, 2*n*) are significantly underestimated and therefore σ(γ, 1*n*) data correspondingly overestimated because many events from (γ, 2*n*) reaction wee interpreted as two (γ, 1*n*). The special way for correction of Saclay data and put them into consistency with Livermore data was used in [11–16].

But after more detailed investigations [18, 19] the doubts appeared concern data reliability because very strange energy dependencies of many σ(γ, 1*n*) obtained at Livermore one can see: many energy regions with physically forbidden negative values of σ(γ, 1*n*). Because of that the problem of data reliability and the task of finding objective physical criteria of data reliability not dependent on the methods of their obtaining became of great interest.

1.1. Objective Physical Criteria of Data Reliability

In order to resolve problems under discussion the new approach for partial reaction cross section evalu-

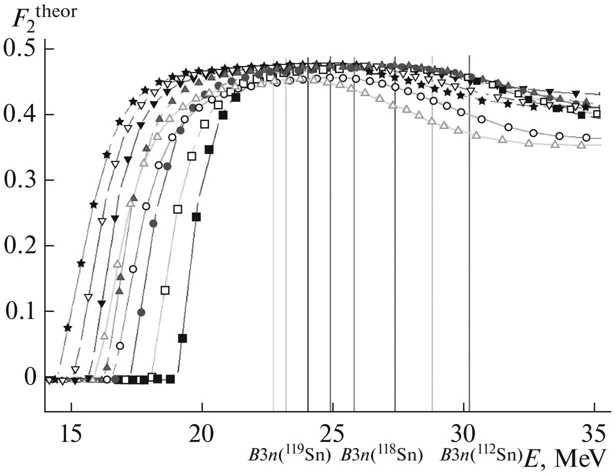


Fig. 1. Energy dependencies of F_2^{theor} calculated [20, 21] for Sn isotopes: A = 112 (closed squares), 114 (open squares), 116 (closed circles) 117 (open circles), 118 (closed triangles) 119 (open triangles), 120 (inverted closed triangles), 122 (inverted open triangles), and 124 (stars). Thresholds $B3n$ of $\sigma(\gamma, 3n)$ are shown for ^{119}Sn (22.8 MeV), ^{118}Sn (25.8 MeV), and ^{112}Sn (30.2 MeV).

ation was developed [18, 19]. It was proposed to use as objective physical criteria of partial photoneutron reaction cross sections reliability the transition multiplicity functions—the ratios of definite partial reaction cross sections to that of neutron yield reaction

$$F_i = \sigma(\gamma, in)/\sigma(\gamma, Sn) \\ = \sigma(\gamma, in)/\sigma[(\gamma, 1n) + 2(\gamma, 2n) + 3(\gamma,\ 3n)\ + \ldots]. \tag{6}$$

The transitional multiplicity functions F_i introduced present simple, objective, and physical criteria for identification the systematic uncertainties in cross sections of partial reactions. According to (6) F_1 is a ratio of $\sigma(\gamma,\ 1n)$ to a sum of itself and $2\sigma(\gamma,\ 2n)$ + $3\sigma(\gamma, 3n)$ and, therefore, can never be greater than 1.00; F_2 is a ratio of $\sigma(\gamma,\ 2n)$ to a sum of itself and $\sigma(\gamma, 1n)$ + $3\sigma(\gamma,\ 3n)$ and, therefore, can never be greater than 0.50; F_3 should be <0.33, and so on. F_i values larger than top limits mentioned mean that sorting of neutrons between partial reactions with correspondent multiplicities were carried out erroneously and therefore those reactions cross sections obtained were not reliable.

In Fig. 1 the results of F_2^{theor} calculations in the frame of combined model of photonuclear reactions [19, 20] for several isotopes of Sn are presented. Combined model is the exciton pre-equilibrium model based on Fermi-gas densities and taking into account the effects of nucleus deformation and its GDR isospin splitting. It is well tested in describing experimental data for medium and heavy nuclei. In accordance with definition (6) natural and physically reliable energy dependences of F_i should be the following:

—Below the (γ, 2n) reaction threshold B2n only (γ, 1n) reaction is possible: F_1 should not be larger 1.00; $F_2 = F_3 = \ldots = 0$;

—Above $B2n$ both (γ, 1n) and (γ, 2n) reactions are possible: F_2 increases due to competition between decreasing $\sigma(\gamma, 1n)$ and increasing $\sigma(\gamma, 2n)$, approaching the physical limit of 0.50, but never reaching it because of a high-energy part in $\sigma(\gamma, 1n)$;

—Above the $B3n$ threshold the (γ, 3n) reaction is also possible, F_3 increases in competition with decreasing $\sigma(\gamma,\ 2n)$ but should not be larger 0.33, F_2 decreases due to a $3\sigma(\gamma,\ 3n)$ term in denominator of (6), etc.

Additionally it should be underlined that in accordance with definition (6) ratios F_i include only the cross section terms and therefore should be certainly positive. Negative values also mean that data are not reliable.

In investigations [15, 16, 18, 19, 22–25] using proposed criteria it was found out that experimental partial photoneutron reaction cross sections obtained using both bremsstrahlung and quasimonoenergetic annihilation photons for many medium and heavy nuclei (^{63,65}Cu, ^{80}Se, ^{90,91,94}Zr, ^{115}In, ^{112,114,116,117,118,119,120,122,124}Sn, ^{133}Cs, ^{138}Ba, ^{159}Tb, ^{181}Ta, ^{186,188,189,190,192}Os, ^{197}Au, ^{208}Pb, ^{209}Bi) are not reliable because in many regions of photon energies they do not satisfy proposed data reliability criteria: F_1^{exp} are negative, F_2^{exp} are negative or larger 0.50, F_3^{exp} are negative or larger 0.33,...etc.

1.2. Results of Experiments Using Quasimonoenergetic Annihilation Photons

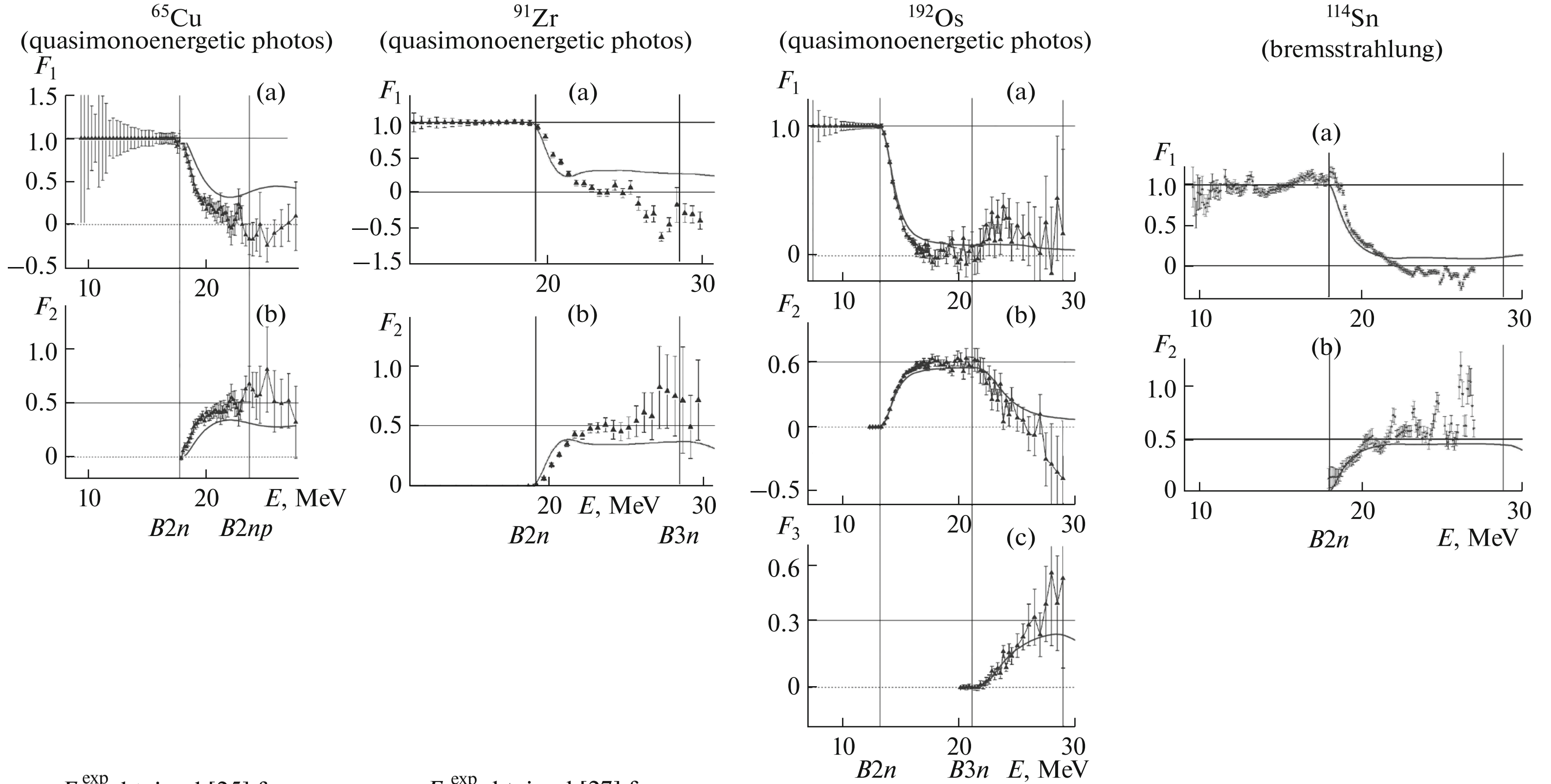
Figure 2 presents examples of typical functions $F_{1,2}^{\text{exp}}$ energy dependencies obtained [25] for experimental data [26] for ^{65}Cu, $F_{1,2}^{\text{exp}}$ obtained [27] for experimental data [28] for ^{91}Zr, and $F_{1,2,3}^{\text{exp}}$ obtained [29] for experimental data [30] for ^{192}Os.

Data are in comparison with results of calculation F_i^{theor} in the frame of combined model [19, 20]: the inconsistencies of the experimental data with reliability criteria are in quite distinct.

For ^{65}Cu one can see that at energies above ~22 MeV, the many function F_1^{exp} values systematically are negative. At the same time the function F_2^{exp} takes physically unreliable values up to 0.80 in excess of the limit of 0.50.

For ^{91}Zr one can see analogous features and correlations at energies above ~25 MeV.

This clear correlations mean that for both nuclei in energy ranges mentioned neutron multiplicity



$F_{1,2}^{\mathrm{exp}}$ obtained [25] for experimental data ([26]), triangles).

$F_{1,2}^{\mathrm{exp}}$ obtained [27] for experimental data ([28]), triangles).

$F_{1,2,3}^{\mathrm{exp}}$ obtained [29] for experimental data ([30]), triangles).

$F_{1,2}^{\mathrm{exp}}$ obtained for experimental data ([31], stars).

Fig. 2. Comparison of functions F_i^{exp} obtained for results of various experiments with those F_i^{theor} calculated in combined model ([19, 20] – lines).

sorting [26, 28] was performed incorrectly: the values $F_2^{\exp} > 0.50$ could appear only due to erroneous addition of extra neutrons with multiplicity two (as a matter of fact, subtracted from neutrons with multiplicity one because "3*n*" channel is closed). This shows clear that experimental sorting of neutrons with multiplicity both 1 and 2 was performed incorrectly.

For ^{192}Os one can see that $F_1^{\exp}$ [30] lies by and near F_1^{theor} but takes small negative values at energies near ~18–22 MeV. $F_2^{\exp}$ has not values noticeably larger limit 0.50. So it can be concluded that sorting of neutrons with multiplicities one and two was performed enough correctly. But at the same time for energies larger ~26 MeV one can see noticeably values of $F_2^{\exp} < 0$ in clear correlation to $F_3^{\exp} > 0.33$. This correlation is indicative of erroneous removing part of neutrons from "2*n*" channel and associating of them with the "3*n*" channel. So both (γ, 2*n*) and (γ, 3*n*) reactions cross sections are not reliable.

1.3. Results of Experiments Using Bremsstrahlung

Figure 2 presents also the typical example of analogous energy dependencies of functions $F_{1,2}^{\exp}$ for nucleus ^{114}Sn obtained bremsstrahlung experimental data [31] and statistical theory corrections for neutron yield reaction (γ, Sn) cross section. One can see that at energies above ~22 MeV, the function $F_1^{\exp}$ values systematically have physically forbidden negative values, obviously going beyond the uncertainties and $F_2^{\exp}$ take physically unreliable values up to 1.20 in excess of the limit of 0.50. This shows clear that these data also could not be considered as to be reliable because incorrect sorting of neutrons with multiplicity one and two.

$F_{1,2}^{\exp}(E)$ are analogous for nuclei ^{112,119}Sn investigated using bremsstrahlung.

1.4. Possible Reasons of Neutron Multiplicity Sorting Shortcomings

It was shown [15, 16, 18, 19, 22–25] that for many nuclei mentioned above energy $F_{1,2,3}^{\exp}(E)$ obtained in different experiments look like those presented in Fig. 2. $F_2^{\exp}$ values are changing from about 0.55 [24] in the case of ^{181}Tb [32] up to 2.00 [22] in the case of ^{159}Tb [33]. The value 2.00 means that partial reaction (γ, 2*n*) contribution is twice larger as the neutron yield reaction (γ, Sn) cross section. Such exotic value indicates unambiguously that the sorting of neutrons with multiplicities one and two was incorrect. In many cases $F_3^{\exp}$ values are noticeably larger than 0.33 or vice versa smaller than 0. It was concluded that many experimental data for partial (and therefore for total photoneutron) reaction cross sections are not reliable.

The reasons for those in experiments both at Saclay and Livermore based of the hypothesis that both neutrons from "2*n*"-channel have energy smaller than one neutron from "1*n*"-channel are the shortcomings of neutron registration methods. At Saclay for neutron energy measurement the large–volume Gd–loaded liquid scintillator was used. It suffers from high background rate, made up large single–neutron events, which introduces large uncertainties in the background subtraction and pile–up corrections [11]. At Livermore "ring–ratio" method was used: neutron counters were putted into paraffin moderator by concentric rings around the target. Low–energy neutrons (supposed, from reaction (γ, 2*n*)) should have enough time for moderation in the way from target to inner ring but high–energy neutrons (supposed from reaction (γ, 1*n*)) should go to the outer ring passing inner ring. But because of multiple scattering there is definite opportunity that high-energy neutron could go back to inner ring. That could certainly unreliably increase the number of neutrons in "2*n*" channel in comparison to correspondent number of neutrons in "1*n*" channel. So the degree of discrepancies between Saclay and Livermore data depends on the energy of photons and, therefore, on energy of neutrons. It means that the relation between the energy of a neutron and its multiplicity could be in fact more complex. A special study [34] showed that mean energy of the 1st neutron from the reaction ^{181}Ta(γ, 2*n*)^{179}Ta is much larger than that of the 2nd neutron (for example, when the photon energy is 25 MeV the mean energy of the 1st neutron is 4.0 MeV, of the 2nd neutron—1.4 MeV). Theoretical calculations in the frame of the model [20, 21] of energy spectra of neutrons from (γ, 1*n*) and (γ, 2*n*) reactions on ^{159}Tb and ^{181}Ta show that in the photon energy ranges $E_\gamma = 12.2$ MeV $< B2n = 14.2$ MeV and $E_\gamma = 19.2$ MeV $> B2n$ shapes of spectra are close. So both Saclay and Livermore methods of neutron kinetic energy measuring could be mistaken generally: if the energy of first chance neutron from reaction (γ, 2*n*) is "enough small" the correspondent event could be correctly and reliably attributed to "2*n*" channel, but if its energy is "enough large" the event could be erroneously and unreliably attributed to "1*n*" channel.

There is an additional serious source of uncertainties in neutron multiplicity determination based on its energy measuring—the contribution of the reaction (γ, 1n1p). In experiments with direct neutron detection under discussion the reaction denoted by (γ, 1*n*) is in fact the [(γ, 1*n*) + (γ, 1*n*1*p*)] one. Obviously, the distribution of excited nucleus energy between the emitted neutron and proton in the (γ, 1*n*1*p*) reaction is expected to be close to that between two neutrons in

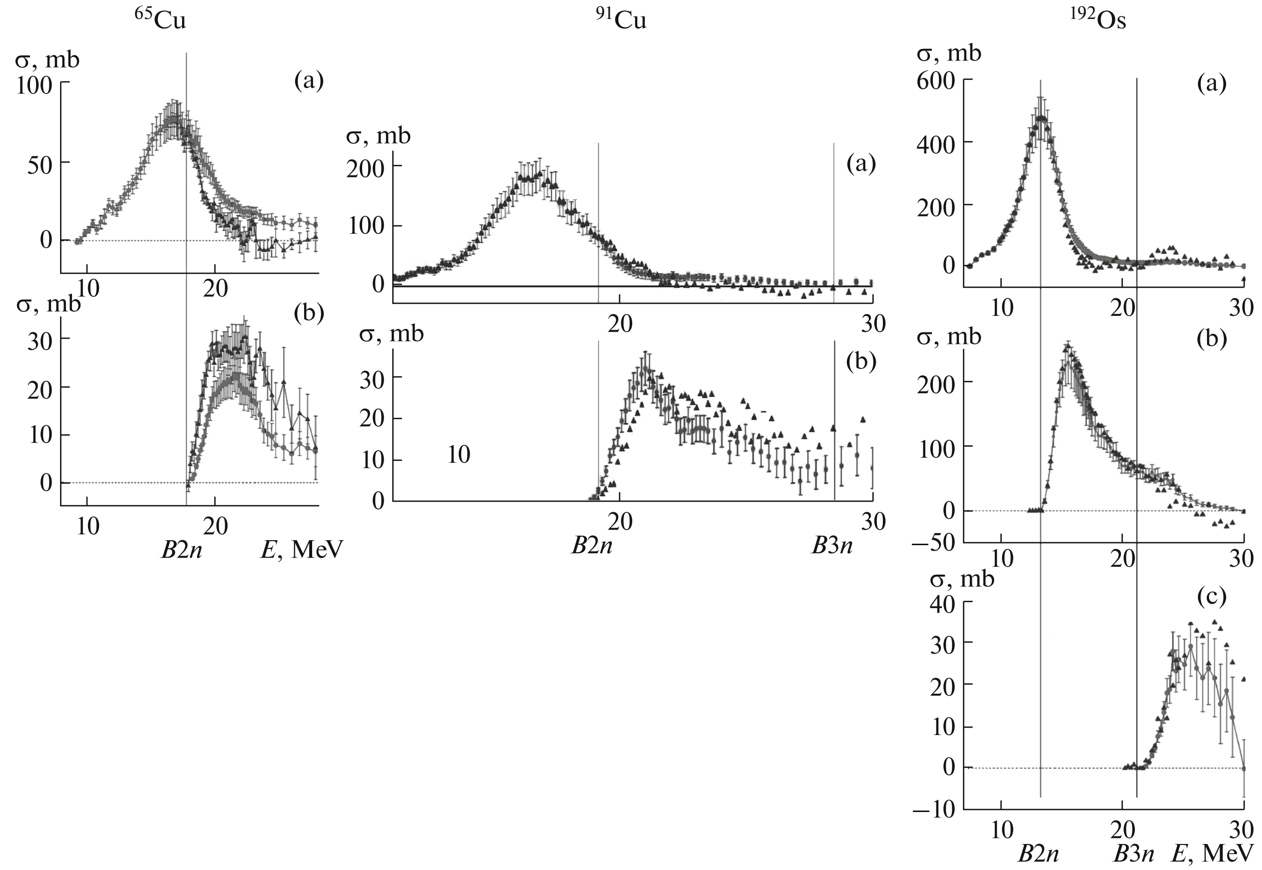


Fig. 3. Comparison of evaluated and experimental cross sections of (γ, 1*n*) and (γ, 2*n*) reactions for ^{65}Cu ([25, 26]) and ^{91}Zr ([27, 28]) and those of (γ, 1*n*), (γ, 2*n*) and (γ, 3*n*) reactions for ^{192}Os ([29, 30]).

the (γ, 2*n*) reaction. However, the neutron multiplicity is one in the (γ, 1*n*1*p*) reaction but two in the (γ, 2*n*) reaction. So the neutrons from those reactions could be mixed [25].

Uncertainties in neutron multiplicity determination based on statistical theory corrections could be appeared in experiments using bremsstraglung because this theory shortcomings. Because of that combined model [20, 21] takes into account several additional effects such as nucleus deformation and giant dipole resonance isospin splitting.

2. EXPERIMENTAL–THEORETICAL METHOD FOR PARTIAL PHOTONEUTRON REACTION CROSS SECTION EVALUATION

With the aim of improving the situation with experimental data the experimental–theoretical method for evaluation of partial reaction cross section satisfied physical criteria was proposed [18, 19] and used for obtaining reliable partial and total photoneutron reaction cross sections for many nuclei under discussion [22–25, 27, 29].

This method is based on the experimental data for neutron yield reaction cross section $\sigma^{\mathrm{exp}}(\gamma, \mathrm{Sn})$ (3) which is separated into partial reaction contributions using functions F_i^{theor} (6) calculated in the frame of combined model of photonuclear reactions [20, 21]:

$$\sigma^{\mathrm{eval}}(\gamma, \mathrm{in}) = F_i^{\mathrm{theor}}(\gamma, \mathrm{in})\sigma^{\mathrm{exp}}(\gamma, \mathrm{Sn}). \qquad (7)$$

The method proposed means that competition of partial reactions is in accordance with equations of the model and the correspondent sum of evaluated cross sections is equal to the experimental data for neutron yield reaction cross section. Therefore evaluated cross sections are free from the problems experimental neutron multiplicity sorting under discussion.

Figure 3 presents the typical results of using proposed method for evaluation (γ, 1*n*) and (γ, 2*n*) reactions cross sections for ^{65}Cu ([25, 26]), ^{91}Zr ([27, 28]) and (γ, 1*n*), (γ, 2*n*) and (γ, 3*n*) reactions cross sections for ^{192}Os ([29, 30]).

Table 2 presents correspondent integrated cross sections of (γ, 1*n*), (γ, 2*n*) and (γ, 3*n*) reactions for ^{65}Cu, ^{91}Zr and ^{192}Os.

One can see that in accordance with F_i^{exp} (Fig. 2) evaluated (γ, 1*n*) and (γ, 2*n*) reactions cross sections for ^{65}Cu and ^{91}Zr deviate from experimental cross sec-

Table 2. Integrated cross sections (MeV mb) of partial reactions for ^{65}Cu, ^{91}Zr and ^{192}Os

Nucleus	Reaction	E^{int}, MeV	Evaluation		Experiment		Deviation, %
^{65}Cu	(γ, 1*n*)	28.0	581.0 ± 13.4	[25]	432.5 ± 13.0	[26]	34
	(γ, 2*n*)		121.9 ± 4.9		200.0 ± 9.5		−64
^{91}Zr	(γ, 1*n*)	28.5	947.5 ± 24.2	[27]	881.8 ± 11.0	[28]	7
	(γ, 2*n*)		143.4 ± 6.0		174.8 ± 5.2		−22
^{192}Os	(γ, 1*n*)	31.0	2032.8 ± 54.5	[29]	1903.1 ± 54.2	[30]	8
	(γ, 2*n*)		1221.8 ± 28.4		1199.7 ± 28.4		2
	(γ, 3*n*)		138.0 ± 15.3		202.8 ± 12.2		−47

tions significantly. For ^{192}Os correspondent differences between those for (γ, 1*n*) and (γ, 2*n*) reactions cross sections are not large and noticeable disagreements one can see only for (γ, 3*n*) reactions cross section.

Evaluated σ^{int}(γ, 1*n*) is 34% larger but σ^{int}(γ, 2*n*) is 64% smaller than Livermore data for ^{65}Cu (Table 2). So the ratio σ^{int}(γ, 2*n*)/σ^{int}(γ, 1*n*) that is very important for many physical processes probabilities estimation for experimental and evaluated data differ about 50%. It is important to point out that evaluated cross sections deviate from Saclay data also. In [16, 22] it was shown on the base of analogous investigations for ^{159}Tb. In relation to data obtained at Livermore [33] the integrated cross section that was evaluated for (γ, 2*n*) reaction decreased by 22%, while its counterpart for (γ, 1*n*) reaction increased by 18% and therefore σ^{int}(γ, 2*n*)/σ^{int}(γ, 1*n*) decreased by 30%. In relation to the Saclay data [35], the integrated cross section that was evaluated for (γ, 2n) reaction increased by 15%, while that for (γ, 1*n*) decreased by 19%. Therefore the ratio σ^{int}(γ, 2*n*)/σ^{int}(γ, 1*n*) increased by 27%.

Analogous data were obtained for many nuclei mentioned above.

The reliability of evaluated partial reaction cross sections was tested in experiment carried out by activation method using bremsstrahlung beam of racetrack microtron with the maximal electron energy 65 MeV [34]. Using high-quality HpGe detector the yields of (γ, 1*n*), (γ, 2*n*), (γ, 3*n*), (γ, 4*n*), (γ, 5*n*), (γ, 6*n*), and (γ, 7*n*) reactions on ^{181}Ta were measured. It was obtained that for yield ratio *Y*(γ, 2*n*)/*Y*(γ, 1*n*) experimental (0.34 ± 0.7) and evaluated (0.33) values are very close but both are noticeably different from Saclay (0.24—data are definitely underestimated) and Livermore (0.42—data are definitely underestimated) values. That confirms that data evaluated in the frame of proposed new experimental—theoretical approach are enough reliable.

3. SUMMARY AND CONCLUSIONS

Experimental data for (γ, 1*n*), (γ, 2*n*) and (γ, 3*n*) reactions for many nuclei (^{63,65}Cu, ^{80}Se, ^{90,91,94}Zr, ^{115}In, ^{112,114,116,117,118,119,120,122,124}Sn, ^{133}Cs, ^{138}Ba, ^{159}Tb, ^{181}Ta, ^{186,188,189,190,192}Os, ^{197}Au, ^{208}Pb, ^{209}Bi) obtained using both quasimonoenergetic annihilation photons and bremsstrahlung were analyzed using objective physical criteria of data reliability. It was found out that many data are not reliable because they are not satisfied proposed criteria.

Using experimental—theoretical method for evaluation of data satisfied reliability criteria new cross section data were obtained. It was shown that evaluated partial reaction cross sections contradict to data obtained using method of neutron multiplicity sorting in experiments with quasimonoenergetic annihilation photons or method of statistical theory corrections in experiments with bremsstrahlung but agree with data obtained using activation method.

Because of large deviations of evaluated cross sections from experimental once many physical effects based on those cross section data should be re-analyzed and/or re-estimated.

For obtaining reliable partial reaction cross section new measurements using alternative methods such as activation methods or methods with detection of produced neutrons in coincidences are needed. Before such experiments carrying out it is useful to use as reliable data those evaluated in the frame of described experimental—theoretical method or another methods without neutron multiplicity sorting.

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