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Cross Sections of the Photoneutron Reaction for ^{141}Pr and ^{186}W Nuclei, Estimated from Physical Criteria of Data Reliability

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Abstract—Using objective physical criteria for data reliability, cross sections of partial photoneutron reactions (γ, 1*n*), (γ, 2*n*) and (γ, 3*n*) that are free of the shortcomings of neutron multiplicity sorting methods used on beams of quasimonoenergetic annihilation photons are obtained for ^{141}Pr and ^{186}W nuclei. Evaluation is performed using the experimental–theoretical method (ETM), based on the experimental cross section of neutron yield reaction $\sigma^{exp}(\gamma, xn) = \sigma^{exp}(\gamma, 1n) + 2\,\sigma^{exp}(\gamma, 2n) + 3\,\sigma^{exp}(\gamma, 3n) + \ldots$ and ratios $F_i^{theor} = \sigma^{theor}(\gamma, in)/\sigma^{theor}(\gamma, xn)$ calculated within the combined model (CM) of photonuclear reactions, which stipulates that $\sigma^{eval}(\gamma, in) = F_i^{theor}\sigma^{exp}(\gamma, xn)$. It is found that for ^{141}Pr and ^{186}W, ratios F_i^{exp} do not contradict the data reliability criteria only at energies up to ~21 and ~22 MeV, respectively. At the same time, there are notable discrepancies between F_i^{theor} and F_i^{exp}, and thus between the evaluated and experimental cross sections of reactions. It is shown that the discrepancies between the evaluated and experimental cross sections are due to the assumed unreliable experimental distribution of neutrons in the channels with multiplicities 1, 2, and 3.

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INTRODUCTION

Experiments [1–8] show that cross sections of partial photoneutron reactions (γ, 1*n*), (γ, 2*n*) and (γ, 3*n*) obtained for large numbers of medium and heavy nuclei of ^{63}Cu to ^{209}Bi in experiments with quasimonoenergetic annihilation photons using photoneutron multiplicity sorting [9–11] fail to meet the objective physical criteria of data reliability. They show that the experimental data contain considerable systematic errors caused the by shortcomings of the methods used to determine the detected neutron multiplicity from their kinetic energies, because the similarity between the energies of neutrons produced in partial reactions (γ, *in*) hampers reliable interpretation of their multiplicity.

The observed systematic errors lead to certain features of the experimental cross sections of reactions (γ, *in*) that make these findings unreliable. On the one hand, physically forbidden negative cross sections are observed in different energy ranges of incoming photons, primarily for reaction (γ, 1*n*). On the other, values are registered that exceed the limits of reliability criteria introduced in [1, 2], e.g., the ratios of cross sections of reaction σ(γ, *in*) to the cross section of neutron yield reaction σ(γ, *xn*):

$$\begin{aligned} F_i^{exp} &= \sigma^{exp}(\gamma, in) / {}^{exp}\sigma(\gamma, xn) \\ &= \sigma^{exp}(g, in) / [\sigma^{exp}(g, 1n) + 2\sigma^{exp}(g, 2n) \\ &\quad + 3\sigma^{exp}(g, 3n) + \ldots]. \end{aligned} \qquad (1)$$

It follows from definition (1) that physically permissible limits F_i^{exp} are 1.00, 0.50, 0.33, ... for respective i = 1, 2, 3, ...

In [1–8], it was shown that the cause of registered systematic errors in experiments, and thus of doubts of their reliability, is the similarity between the energies of neutrons that emerge in different partial reactions. The most widespread source of errors is the groundless transfer of large numbers of neutrons from, e.g., the cross section of reaction (γ, 1*n*) to the that of reaction (γ, 2*n*). The neutron emissions from σ(γ, 1*n*) make this cross section shrink unreliably to physically forbidden negative values. The groundless addition of the same quantity of neutrons to σ(γ, 2*n*) makes this cross section grow to values at which ratios F_2 exceed the limit of physically reliable values 0.50.

Many experimental cross sections of reactions (γ, *in*) [9–11], obtained by means of photoneutron multiplicity sorting based on measuring their kinetic energies, do not meet the above physical reliability criteria. The experimental–theoretical method (ETM) is supposedly [1, 2] able to evaluate reliable cross sections of partial photoneutron reactions, using on the one hand the experimental cross sections of neutron yield reaction

$$\sigma(\gamma, xn) = [\sigma(\gamma, 1n) + 2\sigma(\gamma, 2n) + 3\sigma(\gamma, 3n) + ...], \quad (2)$$

which do not depend on problems with multiplicity, and the rules of the photonuclear reaction combined model (CM) [12–14], which describes cross sections of neutron yield reaction in the ranges of medial and heavy nuclei in good agreement with experimental findings, on the other.

Using ratios (1) calculated according to the CM, we evaluate the cross sections of partial reactions meeting the data reliability criteria:

$$\sigma^{eval}(\gamma, in) = F_i^{theor}\sigma^{exp}(\gamma, xn). \quad (3)$$

The aim of this work was to evaluate reliable cross sections of partial and complete photoneutron reactions on ^{141}Pr and ^{186}W nuclei. The interest in these nuclei is due to the availability of abundant data for them (findings of experiments using beams of quasimonoenergetic annihilation and monoenergetic tagged photons and bremsstrahlung γ-radiation) gained by different means (photoneutron multiplicity sorting, correction of the cross sections of yield reactions in accordance with statistical theory, and activation), which provide ample opportunities for comparing different data from the viewpoint of their reliability.

PHOTONEUTRON REACTIONS FOR THE ^{141}PR NUCLEUS

According to (3), the experimental $\sigma^{exp}(\gamma, xn)$ and theoretical $\sigma^{theor}(\gamma, xn)$ cross sections of neutron yield reaction (2) that best agree with each other [15] should be used in the ETM to evaluate the cross sections of partial reactions that meet the physical reliability criteria. Based on a preliminary analysis of such properties as center of gravity and integral cross section, a small preliminary correction (shift of energy, normalization) was made in [1–8] to the theoretically calculated cross section of a yield reaction chosen for maximum approximation to the experimental parameters.

Data for Reaction ^{141}Pr(γ, 1n)^{140}Pr

With the ^{141}Pr nucleus, preliminary correction of the partial theoretical cross sections was performed in a slightly different way, because the cross sections of reaction (γ, 1*n*) showing quite good agreement with one another for this nucleus were determined in six different experiments [16–21]. Since some of these cross sections were determined by means of activation, and others by measuring the photoneutron energy spectra using a beam of monoenergetic tagged photons, their agreement in the range of the principal maximum shows that the identification of photoneutrons with multiplicity 1 in these experiments is quite reliable. The parameters for correcting the cross sections of yield reaction (2) were therefore determined using the weight average energy center of gravity and integral cross section of reaction ^{141}Pr(γ, 1*n*)^{140}Pr.

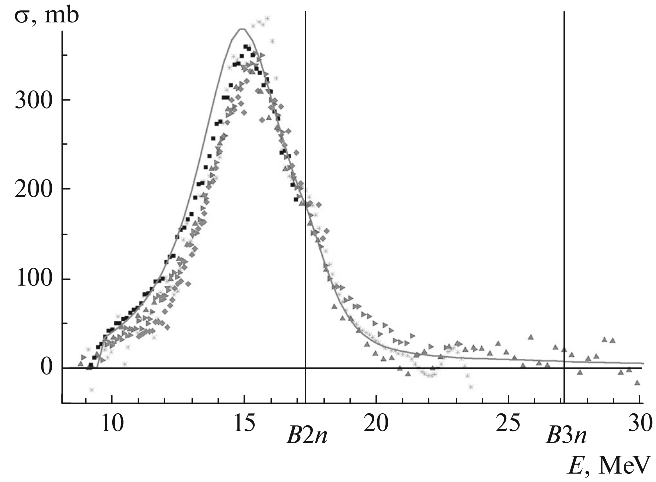

Fig. 1. Theoretical (CM, line) and experimental cross sections of reaction ^{141}Pr(γ, 1*n*) ^{140}Pr: diamonds denote monoenergetic tagged photons [16]; rightward triangles, quasimonoenergetic annihilation photons (activation) [17]; upright triangles, quasimonoenergetic annihilation photons (photoneutron multiplicity sorting) [18]; inverted triangles, quasimonoenergetic annihilation photons (photoneutron multiplicity sorting) [19]; squares, quasimonoenergetic annihilation photons (photoneutron multiplicity sorting) [20]; stars, bremsstrahlung γ-radiation (activation) [21].

Figure 1 compares all of the experimental cross sections of reaction ^{141}Pr(γ, 1*n*)^{140}Pr determined by different means to the cross section theoretically calculated within the CM. Table 1 gives the energy centers of gravity and integral cross sections calculated in different experiments [16–21] for energies up to threshold *B*2*n* of reaction ^{141}Pr(γ, 1*n*)^{139}Pr. It is shown that the experimental data are quite consistent.

Preliminary Correction of Data for Reaction ^{141}Pr(γ, xn)

Table 1 gives the experimental weight averages of the cross sections of reactions (γ, 1*n*) used to preliminarily correct the data in evaluating procedure (3). Since σ(γ, 1*n*), σ(γ, 2*n*) and σ(γ, 3*n*) were obtained only in an experiment performed at Livermore [18], the cross section of yield reaction ^{141}Pr(γ, *xn*) obtained in this experiment was used for further evaluates. According to the results presented in Table 1, both the experimental and theoretical cross sections of reaction (γ, 1*n*) used in the evaluating procedure were corrected

Table 1. Energetic centers of gravity $E^{c.g.}$ and integral cross sections σ^{int} of cross sections of reaction ^{141}Pr(γ, 1n)^{140}Pr, calculated for energies below threshold $B2n$ = 17.3 MeV

Experiment and theory	$E^{c.g.}$, MeV	σ^{int}, MeV mb
Theory [12–14]	14.45 ± 1.82	1585.92 ± 40.83
Tagged photons [16]	14.70 ± 0.45	1289.0 5± 7.57
Annihilation photons, activation method [17]	14.64 ± 0.46	1345.34 ± 7.82
Annihilation photons, photoneutron multiplicity sorting [18]	14.53 ± 0.52	1348.73 ± 9.82
Annihilation photons, photoneutron multiplicity sorting [19]	14.27 ± 0.34	1438.26 ± 6.52
Annihilation photons, photoneutron multiplicity sorting [20]	14.44 ± 0.17	1492.76 ± 3.22
Bremsstrahlung γ-radiation, activation method [21]	14.68 ± 0.58	1427.14 ± 10.40
Weight averages over experimental data	14.53 ± 0.62	1418.17 ± 12.31

to make their energy centers of gravity and integral cross sections coincide, in the range of principal maximum, with the weight averages determined earlier from data on the principal maximum in reaction (γ, 1n). The experimental cross section in [18] was shifted 0.01 MeV toward smaller energies and multiplied by coefficient 1.04, and the cross section theoretically calculated within the CM was shifted 0.09 MeV toward higher energies and multiplied by the coefficient 0.90. The results from our preliminary correction are presented in Fig. 2.

Criteria for the Reliability of Experimental Data for Cross Sections of Partial Photoneutron Reactions on the ^{141}Pr Nucleus

Figure 3 compares the energy dependences of ratios F_i^{exp} (1) obtained using the data in [18] to F_i^{theor} calculated within CM. It is shown that even though energy dependences F_i^{exp} generally do not contradict our data reliability criteria within the limits of error (no strongly pronounced negative values or values

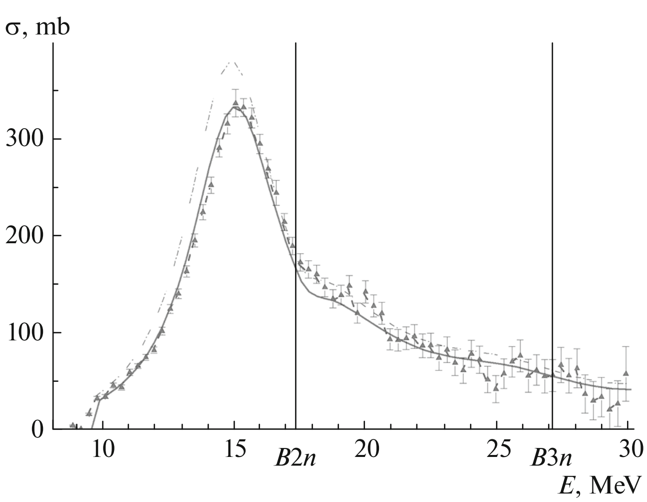

Fig. 2. Experimental [18] (triangles) and theoretical (CM) (before (dashed-and-dotted line) and after (solid line) correction) cross sections of photoneutron yield reaction ^{141}Pr (γ, xn).

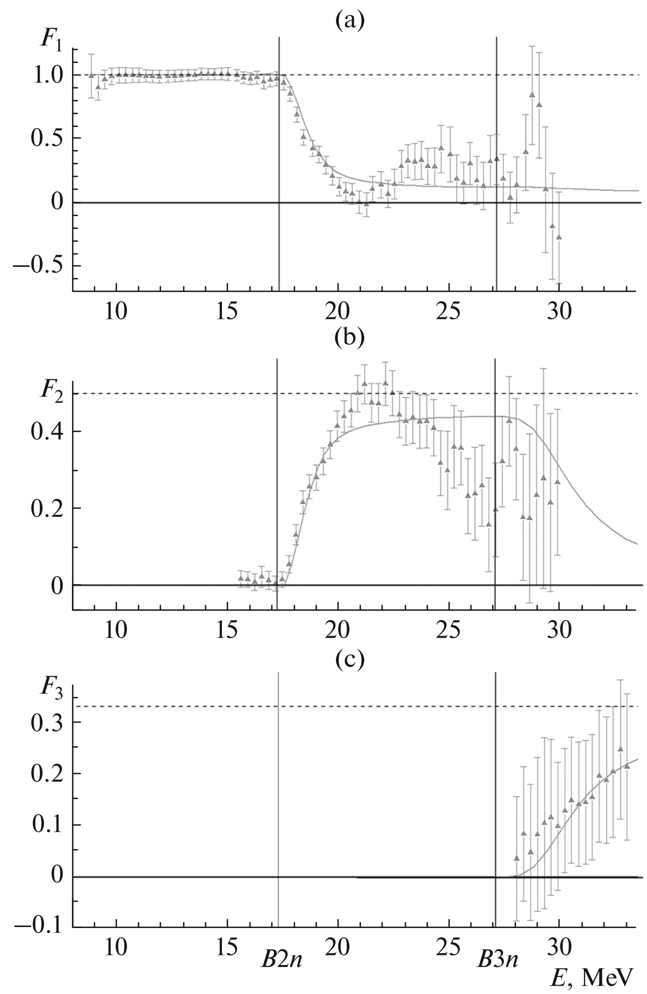

Fig. 3. F_i^{exp} ((a), (b), (c) for i = 1, 2, 3) obtained from the experimental data in [18] (triangles) and F_i^{theor} (CM) for the ^{141}Pr nucleus.

exceeding the reliable upper limits are observed), they differ considerably from F_i^{theor}.

This is especially true for ratio F_2. There are doubts concerning the reliability of data in the energy range of ~21–23 MeV, due to their proximity to limit 0.50. The data for the energy range of ~23–27 MeV are unreliable, since according to definition (1), there are no physically valid reasons for such a sharp decrease in F_2 at several MeV before channel (γ, 3*n*) is opened. In connection with the above, there should be considerable discrepancies between the evaluated and experimental cross sections of reaction (γ, 2*n*), as is confirmed by the data displayed in Fig. 4.

In the energy range of ~28–30 MeV, F_2^{exp} generally approaches F_2^{theor}; however, the observed considerable spread in F_2^{exp} also raises doubts concerning the reliability of the data, especially since this spread appears to be in antiphase with that of F_1^{exp}.

Energy dependences of ratios F_1^{exp} and F_1^{theor} are fairly close only in the energy range below ~22 MeV, which correlates with the similar dependence of the cross section of reaction ^{141}Pr(γ, 1*n*)^{140}Pr in the energy range below *B*2*n*. Considerable discrepancies (see Fig. 4) are observed at higher energies.

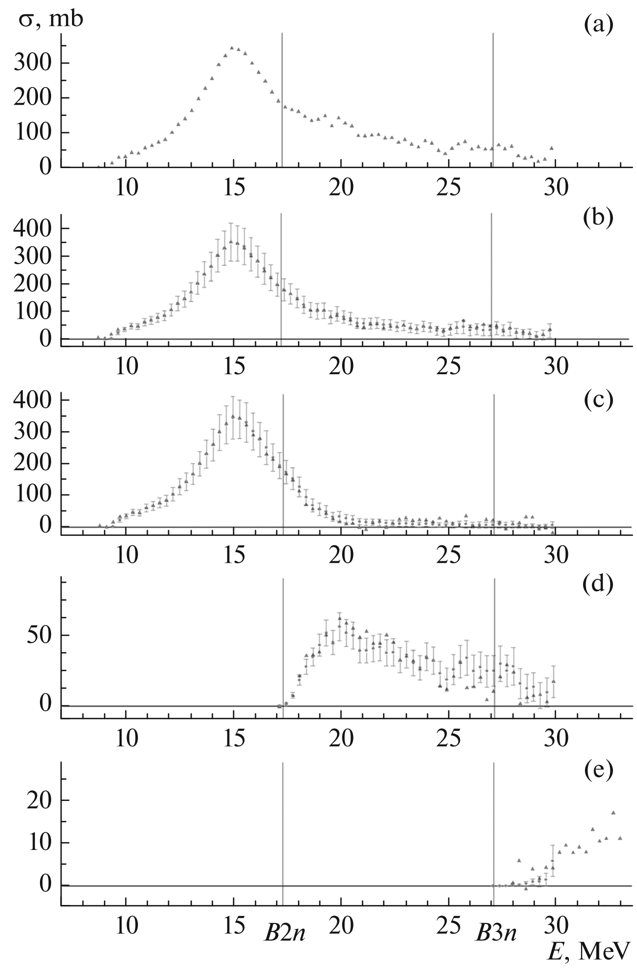

Fig. 4. Evaluated (points) and experimental [18] (triangles) cross sections of complete and partial photoneutron reactions on the ^{141}Pr nucleus: (a) σ(γ, *xn*); (b) σ(γ, *sn*); (c) σ(γ, 1*n*); (d) σ(γ, 2*n*); (e) σ(γ, 3*n*).

Evaluated Data for the Cross Sections of Photoneutron Reactions on the ^{141}Pr Nucleus

Figure 4 compares the data evaluated in the ETM using objective physical criteria of data reliability and the experimental [18] cross sections of partial reactions (γ, 1*n*), (γ, 2*n*) and (γ, 3*n*), and complete photoneutron reaction

$$\sigma(\gamma, sn) = \sigma(\gamma, 1n) + \sigma(\gamma, 2n) + \sigma(\gamma, 3n) + \ldots \quad (4)$$

Table 2 shows the respective data for integral cross sections calculated for different energy ranges. According to the above, the evaluated cross sections (measured in MeV mb, 1412.2 ± 72.9, 1412.3 ± 75.0) in the energy ranges below 17.3 MeV for reactions (γ, 1*n*) and (γ, *sn*) are fairly close to the weight average (1418.17 ± 12.31). This shows that our evaluation of the cross sections of partial photoneutron reactions on the ^{141}Pr nucleus, made using data reliability criteria (1) and ETM (3), provides reliable data.

Table 2. Integral sections σ^{int} of evaluated cross sections of complete and partial photoneutron reactions on the ^{141}Pr nucleus, compared to the experimental data in [18]

Reaction	$E^{\text{int}} = B2n = 17.3$ MeV		$E^{\text{int}} = B3n = 27.1$ MeV		$E^{\text{int}} = 30.0$ MeV	
	experiment	evaluation	experiment	evaluation	experiment	evaluation
(γ, *xn*)*	1418.2 ± 15.4	1418.2 ± 15.4	2396.4 ± 31.3	2396.4 ± 31.3	2526.7 ± 40.1	2526.7 ± 40.1
(γ, *sn*)	1411.3 ± 14.7	1412.3 ± 75.0	2070.4 ± 27.2	2065.2 ± 87.9	2150.6 ± 34.0	2136.5 ± 90.8
(γ, 1*n*)	1406.5 ± 16.1	1412.2 ± 72.9	1728.4 ± 29.8	1740.0 ± 79.4	1752.9 ± 36.5	1755.7 ± 79.9
(γ, 2*n*)			359.8 ± 16.7	325.2 ± 18.2	397.0 ± 14.0	377.5 ± 22.0
(γ, 3*n*)					7.4 ± 4.7	3.3 ± 1.8

* Initial value for evaluating the experimental cross section of the neutron yield reaction in [18].

Table 3. Energetic centers of gravity $E^{c.g.}$ and integral cross sections σ^{int} of the cross sections of reaction (γ, xn) for the ^{186}W nucleus [22, 23]

Energy range	$E^{c.g.}$, MeV	σ^{int}, MeV mb	$E^{c.g.}$, MeV	σ^{int}, MeV mb	$E^{c.g.}$, MeV	σ^{int}, MeV mb
	$E^{int} = B2n = 12.9$ MeV		$E^{int} = B2n = 20.4$ MeV		$E^{int} = 28.5$ MeV	
Experiment [22]	11.64 ± 0.36	700.06 ± 5.35	15.13 ± 0.45	3612.99 ± 16.64	14.93 ± 0.40	4439.87 ± 36.63
Theory, initial (CM)	11.50 ± 1.45	753.13 ± 27.80	14.90 ± 1.87	3632.99 ± 76.81	16.92 ± 2.20	4690.25 ± 81.35
Theory, corr.	11.53 ± 1.83	751.29 ± 34.82	15.06 ± 2.38	3619.18 ± 95.97	17.09 ± 2.80	4668.61 ± 101.92
Experiment [23]	11.55 ± 0.44	808.67 ± 7.91	14.98 ± 0.71	3773.00 ± 30.80		
Experiment, corr [23]	11.55 ± 0.57	741.63 ± 9.71	14.95 ± 0.90	3460.26 ± 34.60		

In all three considered energy ranges, the reliable evaluated cross section of reaction $(\gamma, 1n)$ is slightly larger than the experimental cross section. In contrast, the reliable evaluated cross section of reaction $(\gamma, 2n)$ is slightly smaller than the experimental cross section. This indicates there are certain systematic errors in the method of experimental photoneutron multiplicity sorting [18].

Note that in the approach described above, data for the cross section of reaction $(\gamma, 3n)$ were evaluated only for the energy range below 30 MeV, since the experimental cross section of yield reaction (γ, xn) was determined only up to this energy. In this energy range, the evaluated cross section had greater statistical errors and was more than 50% smaller than the experimental cross section (Table 2). Serious doubts therefore arise concerning the reliability of the experimental cross section [18] of reaction $(\gamma, 3n)$. The way the cross section of reaction $(\gamma, 3n)$ was determined in the energy range below 30 MeV is not quite clear; neither is why the cross sections of reactions $(\gamma, 2n)$, $(\gamma, 1n)$, and (γ, xn) were not determined at energies below this energy. At the same time, it should be noted that F_3^{exp} and F_3^{theor} in the energy range below 30–33 MeV (Fig. 3c) are quite consistent.

PHOTONEUTRON REACTIONS FOR THE ^{186}W NUCLEUS

The situation with experimental data is quite poor for the ^{186}W nucleus, relative to the one discussed above for the ^{141}Pr nucleus. The cross sections of partial reactions $(\gamma, 1n)$, $(\gamma, 2n)$ and $(\gamma, 3n)$ and of the complete photoneutron reaction (γ, sn) and the cross section of yield reaction (γ, xn) were obtained in a single experiment performed using a beam of quasimonoenergetic annihilation photons with photoneutron multiplicity sorting [22]. In addition, we obtained the cross sections of the complete photoneutron reaction (γ, sn) and yield reaction (γ, xn) at energies below ~19 MeV using a beam of bremsstrahlung γ-radiation [23] (the former was determined from the latter by means of correction according to statistical theory). The cross sections of the two reactions allow us to obtain cross sections of reactions $(\gamma, 1n)$ and $(\gamma, 2n)$ in the energy range below $B3n$ using simple relations ((2) and (4)):

$$\sigma(\gamma, 2n) = \sigma(\gamma, xn) - \sigma(\gamma, sn); \quad (5)$$

$$\sigma(\gamma, 1n) = \sigma(\gamma, sn) - \sigma(\gamma, 2n). \quad (6)$$

Reliable cross sections of partial reactions on the ^{186}W nucleus were evaluated according to the conventional procedure used in many other cases [1–8]: joint preliminary correction of the theoretical cross section of yield reaction (γ, xn) to obtain the best correlation with the respective experimental cross section, with subsequent use of ETM (3) to evaluate the cross sections of partial reactions.

Preliminary Correction of Data for Reaction $^{186}W(\gamma, xn)$

Experimental [22] and theoretical (CM) data before and after preliminary correction (the respective energy centers of gravity and integral cross sections are presented in Table 3) are given in Fig. 5. In addition, the cross sections of yield reaction ^{186}W(γ, xn) [23] are presented in Table 3. After additional correction, they agree with the experimental [22] and theoretical (CM) data in the energy range up to $B3n = 20.36$ MeV. To achieve the best agreement with the experimental cross sections [22], the theoretical cross section found in the CM was shifted 0.24 MeV toward higher energies and was corrected slightly in value (the multiplier was 0.996). To achieve agreement with the cross section in [22], the cross section in [23] was shifted 0.05 MeV toward lower energies and multiplied by coefficient 0.92.

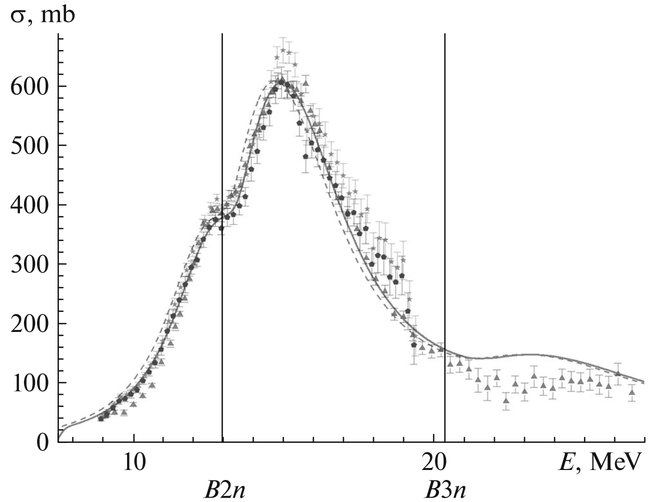

Fig. 5. Theoretical (CM) before (dashed line) and after (solid line) correction and experimental [22] (triangles) and [23] (stars denote before correction; pentagons, after correction) cross sections of photoneutron yield reaction ^{186}W(γ, *xn*).

Experimental Reliability Criteria for the Cross Sections of Partial Photoneutron Reactions on the ^{186}W Nucleus

Figure 6 compares the energy dependences of ratios F_i^{exp} (1) obtained using the data in [22, 23] to F_i^{theor} (CM).

The energy dependences of ratios F_i^{exp} [22] in the energy ranges below ~22 MeV clearly do not contradict our reliability criteria within the range of error: there are no strongly pronounced negative values or values exceeding the upper limits, and their deviations from F_i^{theor} are small. At the same time, the data for the energy range ~22–25 MeV raise certain doubts: a correlation between F_i^{exp} fluctuations in relation to F_i^{theor} is observed, and F_1^{exp} is negative at energies close to 22 MeV; F_2^{exp} differs notably from F_2^{theor}. In the energy range of ~23–25 MeV, the notable excess of F_1^{exp} over F_1^{theor} and of F_3^{exp} over F_3^{theor} correlates with that of F_2^{theor} over F_2^{exp} (with negative values at an energy of 24 MeV).

The above shows that photoneutron multiplicity sorting in [22] was performed with sufficient reliability only at energies below ~22 MeV, while ratios F_i^{exp} [23] obtained using the experimental data for a beam of bremsstrahlung γ-radiation with correction of the cross section of the yield reaction according to statistical theory was generally consistent with the physical reliability criteria. At the same time, in energy ranges ~13.0–15.0 MeV and ~16.0–19.0 MeV, certain correlating deviations of F_1^{exp} from F_1^{theor} and of F_2^{exp} from F_2^{theor} were observed, which is characteristic of the considered systematic errors.

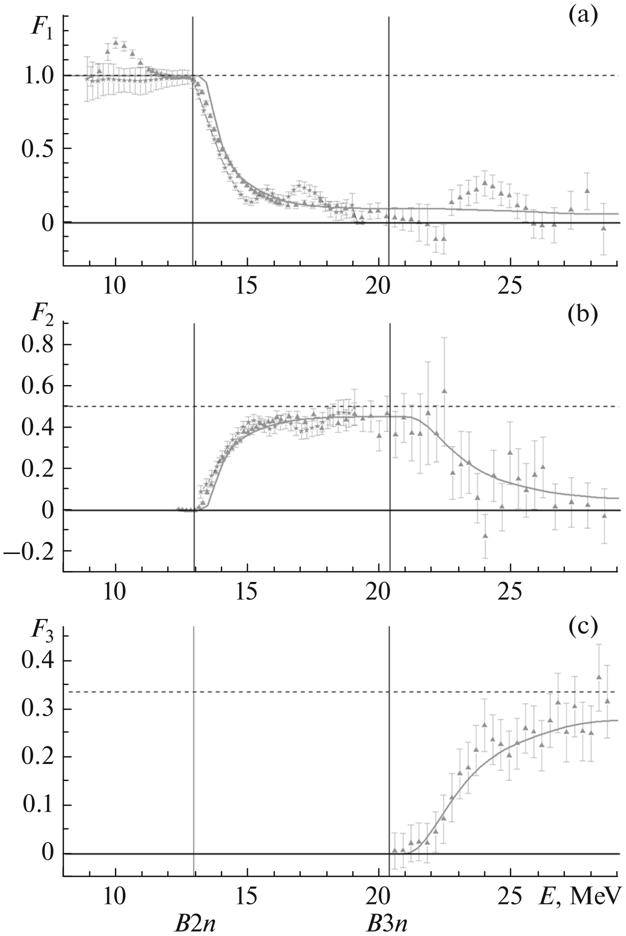

Fig. 6. F_i^{exp} ((a), (b), (c) for $i = 1, 2, 3$) obtained using the experimental data in [22] (triangles), [23] (stars), and F_i^{theor} (CM) for the ^{186}W nucleus.

Evaluated Data for the Cross Sections of Photoneutron Reactions on the ^{186}W Nucleus

Figure 7 compares the cross sections of partial reactions (γ, 1*n*), (γ, 2*n*) and (γ, 3*n*), and complete photoneutron reaction (4), evaluated using the approach described above, to the experimental data in [22, 23]. Table 4 shows respective data for the integral cross sections calculated for different energy ranges.

It should be noted that in agreement with the above on the nature of the discussed systematic errors of the methods used in [22, 23] to determine the cross sections of partial reactions, the integral evaluated cross section of reaction (γ, 1*n*) appears to be slightly larger, and the integral evaluated cross section of reaction (γ, 2*n*) slightly smaller, than the respective experimental cross sections, as was observed for the ^{141}Pr nucleus.

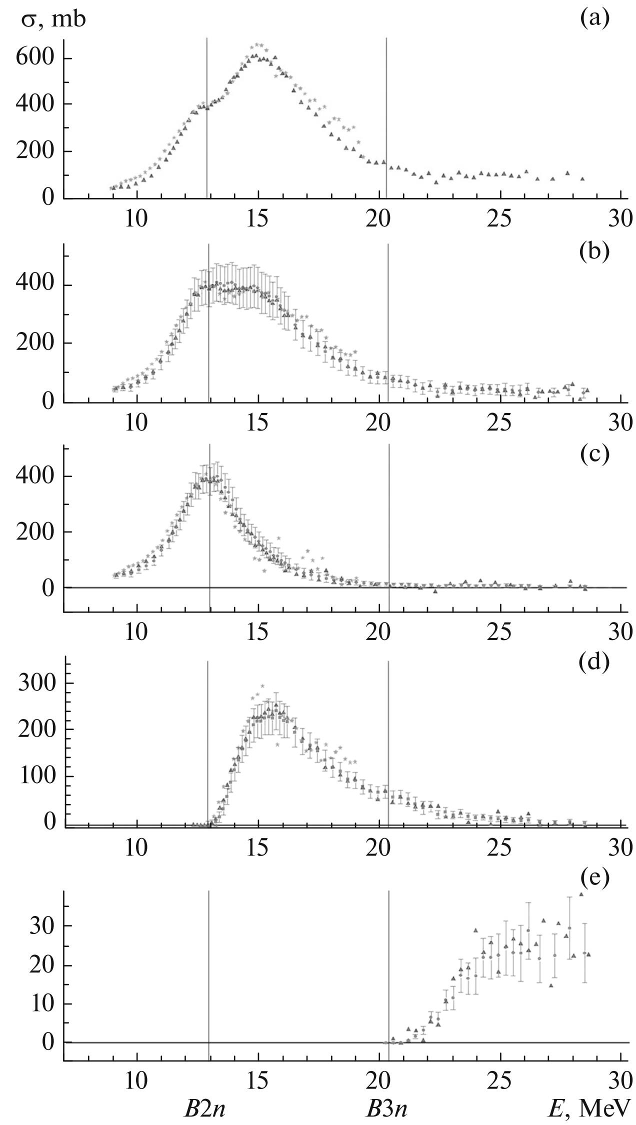

Fig. 7. Evaluated (points) and experimental (triangles denote [22], stars denote [23]) cross sections of complete and partial photoneutron reactions on the ^{186}W nucleus: (a) σ(γ, *xn*); (b) σ(γ, *sn*); (c) σ(γ, 1*n*); (d) σ(γ, 2*n*); (e) σ(γ, 3*n*).

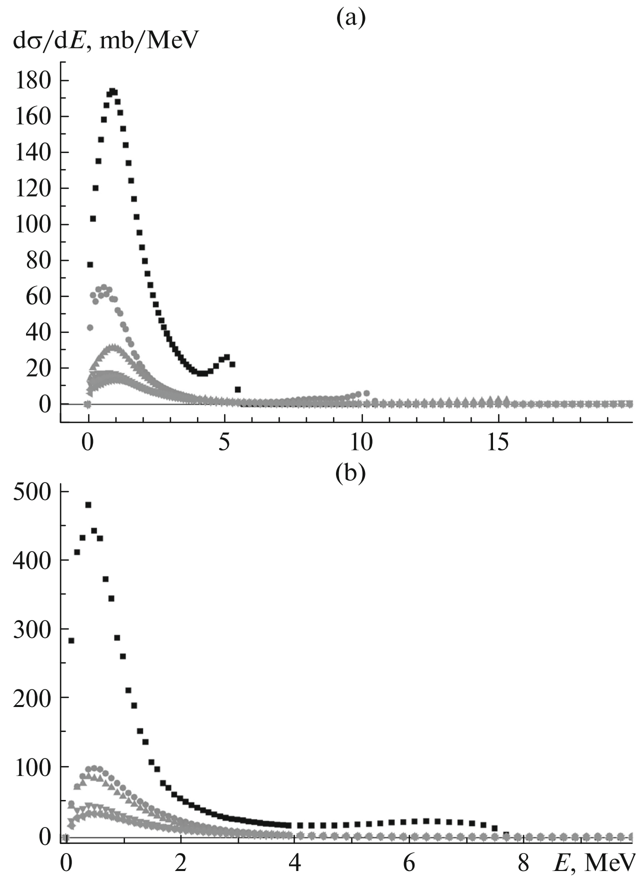

Fig. 8. Energy spectra of photoneutrons emitted from (a) ^{141}Pr and (b) ^{186}W nuclei at different excitation energies: squares denote 15 MeV; dots, 20 MeV; upright triangles, 25 MeV; inverted triangles, 30 MeV; rightward triangles, 40 MeV.

CONCLUSIONS

Our studies suggest that the experimental data on the cross sections of partial photoneutron reactions on the considered nuclei are determined with sufficient reliably only at rather low energies (up to ~21 MeV for the ^{141}Pr nucleus, and up to ~22 MeV for the ^{186}W nucleus).

At higher energies, the cross sections of partial reactions (γ, 1*n*), (γ, 2*n*) and (γ, 3*n*) on both considered nuclei contain considerable systematic errors. Even though no appreciable inconsistencies with the physical criteria for data reliability were observed, the experimental values of ratios F_2^{exp} differ notably from F_2^{theor}. According to [1–8], these errors are due to the unreliable redistribution of neutrons among channels 1*n*, 2*n* and 3*n*. As a result, the evaluated cross sections of reaction (γ, 1*n*) appear slightly larger than the experimental cross sections for both nuclei at all of the considered energies. In contrast, the evaluated cross sections of reaction (γ, 2*n*) are slightly smaller than the experimental cross sections [18, 22, 23]. The evaluated reliable cross sections of reaction (γ, 3*n*) for both nuclei appear noticeably smaller than the experimental cross sections.

Our studies of the photodisintegration of ^{141}Pr and ^{186}W nuclei confirm the conclusions in [1–8] that the specific shortcomings of the method are the main reason for the discussed systematic errors of cross sections of partial photoneutron reactions determined by means of neutron multiplicity sorting. The similarity between the energies of neutrons from different reactions greatly complicates the procedure for determining neutron multiplicity from this energy and makes this procedure ambiguous. Figure 8 displays the calculated CM inclusive spectra of neutrons emitted by the

Table 4. Integral cross sections σ^{int} of the evaluated cross sections of complete and partial photoneutron reactions on the ^{186}W nucleus, compared to the experimental data in [22, 23] for different energy ranges

E^{int}, MeV	$B2n = 12.9$	$B3n = 20.4$	28.5
Reaction		(γ, *xn*)	
Experiment [22]	700.06 ± 5.35*	3612.99 ± 16.64*	4439.87 ± 36.63*
Experiment [23]	741.78 ± 9.71	3625.33 ± 45.39**	
Reaction		(γ, *sn*)	
Experiment [22]	711.49 ± 5.34	2583.96 ± 12.94	2961.16 ± 20.71
Evaluation	699.46 ± 32.15	2606.99 ± 77.97	2986.47 ± 85.88
Experiment [23]	725.11 ± 9.59	2628.93 ± 10.88**	
Reaction		(γ, 1*n*)	
Experiment [22]	720.43 ± 5.40	1536.74 ± 18.41	1607.36 ± 32.33
Evaluation	699.26 ± 27.25	1594.52 ± 45.77	1662.34 ± 47.14
Experiment [23]	724.54 ± 23.95	1510.69 ± 48.26**	
Reaction		(γ, 2*n*)	
Experiment [22]		1040.43 ± 10.73	1201.46 ± 24.81
Evaluation		1012.53 ± 37.20	1190.43 ± 40.57
Experiment [23]		1123.21 ± 43.19**	
Reaction		(γ, 3*n*)	
Experiment [22]			144.11 ± 10.73
Evaluation			133.76 ± 11.10

* Initial value for evaluating the experimental cross section of the neutron yield reaction in [22].
** Integral cross sections determined up to energy E^{int} = 19.0 MeV (the maximum in the experiment in [23]).

considered nuclei in states excited at different energies. In the ^{141}Pr nucleus, energies 15 and 20 MeV thus correspond (Fig. 4) to the maxima of the cross sections of reactions (γ, 1*n*) and (γ, 2*n*); in the ^{186}W nucleus, energies 15 and 25 MeV correspond to the maxima (Fig. 7) of the cross sections of reactions (γ, 2*n*) and (γ, 3*n*). The profiles and average energies of the four spectra are quite similar, as are positions of the principal peaks (~0.7–1.0 MeV). The reason for this is that once their neutrons are gone, the final nuclei are left not only in the principal state but in many other excited states, making the neutron energy's relation to multiplicity unclear.

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