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NUCLEI
Experiment

Photodisintegration of the Isotopes ^{186,188,189,190,192}Os: Similarities and Distinctions

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Abstract—In addition to the results obtained earlier for the isotopes ^{188,189}Os, experimental data on the photodisintegration of the isotopes ^{186,190,192}Os are analyzed on the basis of specially introduced objective criteria of reliability of data on the cross sections for partial photoneutron reactions. It is found that the $(\gamma, 1n)$, $(\gamma, 2n)$, and $(\gamma, 3n)$ cross sections for each isotope satisfy differently or, on the contrary, do not satisfy the data-reliability criteria. In many cases, the multiplicity transition functions specified as the ratios $F_i = \sigma(\gamma, in)/\sigma(\gamma, xn)$ of the cross sections for the (γ, in) partial reactions to the neutron-yield reaction cross section $\sigma(\gamma, xn) = \sigma(\gamma, 1n) + 2\sigma(\gamma, 2n) + 3\sigma(\gamma, 3n) + \ldots$ have values that are physically unreliable by definition. It is shown that ambiguities in the dependence of significant systematic uncertainties in experimentally determined neutron multiplicities on the measured kinetic energies is the reason for this. The dependence of these uncertainties on the energy spectra of neutrons is analyzed. For the isotopes ^{186,190,192}Os, new evaluated data satisfying the data-reliability criteria are obtained for the cross sections for partial and total photoneutron reactions.

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1. INTRODUCTION

In [1], our group performed an analysis of experimental data from [2] on the photodisintegration of the isotopes ^{188,189}Os. We found that, in just the same way as in the case of many other nuclei (^{90}Zr, ^{115}In, ^{112,114,116,117,118,119,120,122,124}Sn, ^{159}Tb, ^{181}Ta, and ^{197}Au) studied earlier [3–7] in beams of quasimonoenergetic photons from the annihilation process by the method of photoneutron multiplicity sorting, experimental cross sections for the $(\gamma, 1n)$, $(\gamma, 2n)$, and $(\gamma, 3n)$ partial reactions on the isotopes ^{188,189}Os involve significant systematic errors. It was established that they were caused by ambiguities in determining the multiplicities of neutrons from different reactions.

Because of these systematic uncertainties, it turns out that, in various regions of incident-photon energies, the transition multiplicity functions introduced as criteria of reliability of data on cross sections for partial photoneutron reactions in the form of the ratio

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

take values exceeding limits physically allowed for them by definition—1.00, 0.50, 0.33, ... for, respectively, $i = 1, 2, 3, \ldots$.

The appearance of values above these limits means that neutron multiplicity sorting was incorrect in the aforementioned experiments. Further, values of, for example, the function F_2 above the limiting value of 0.50 correlate with the appearance of physically forbidden negative values of the $(\gamma, 1n)$ cross section at the same energies and, accordingly, in the energy dependence of the function F_1. This is due to unjustifiably associating a sizable fraction of neutrons from the $1n$ channel with the $2n$ channel, with the result that the $(\gamma, 1n)$ cross section decreases to physically forbidden negative values, while the $(\gamma, 2n)$ cross section grows unjustifiably to such an extent that the function F_2 becomes greater than 0.50. At energies above $(\gamma, 3n)$ threshold $B3n$, there was an illegitimate redistribution of part of the neutrons between the $3n$ and $2n$ channels, as well as between the $3n$ and $1n$ channels.

With the aim of obtaining data in which cross sections for partial photoneutron reactions would be free from the aforementioned systematic errors and for which the reliability criteria would hold, an experimental—theoretical method for evaluating cross sections that is free from shortcomings of the experimental methods of neutron multiplicity sorting was proposed in [3, 4]. This method is based on employing, in the evaluation of partial-reaction

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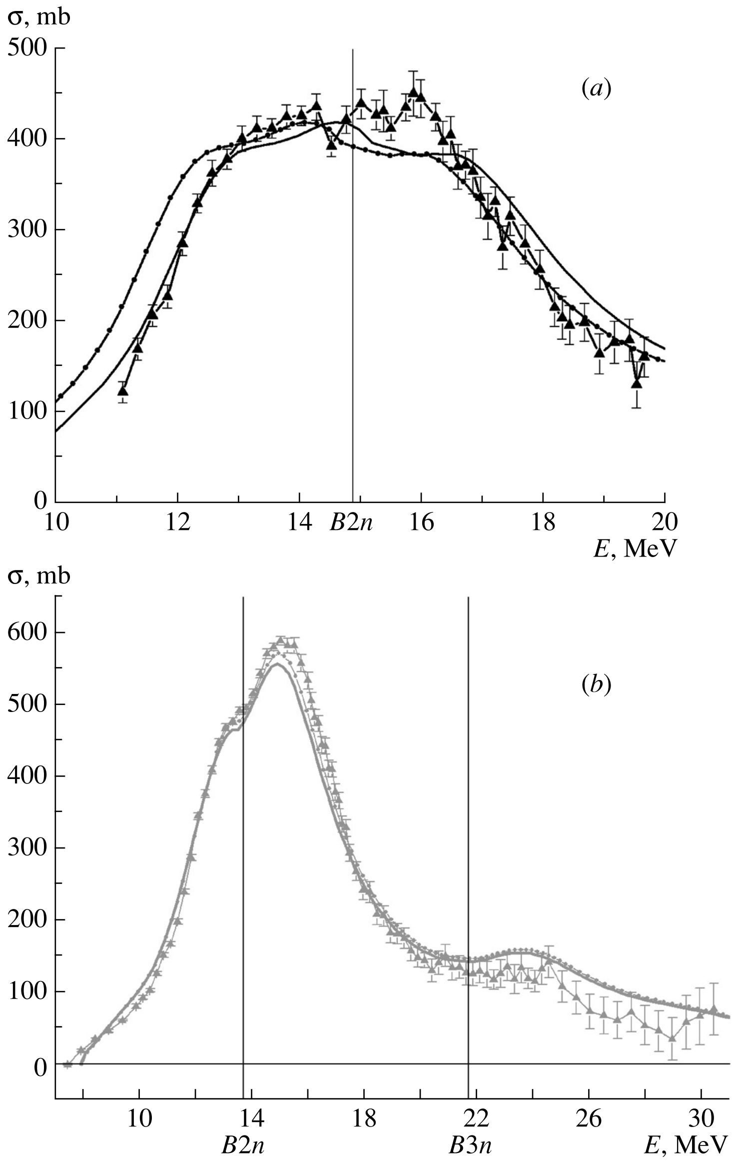

Fig. 1. Theoretical [8, 9] (solid curve) input and (closed circles) corrected cross sections along with (triangles) the experimental cross section [2] for neutron production in the (γ, xn) reaction on (*a*) ^{186}Os and (*b*) ^{190}Os nuclei.

cross sections, as the input experimental neutron-production cross section the only reaction

$$\sigma(\gamma, xn) \approx \sigma(\gamma, 1n) + 2\sigma(\gamma, 2n) + 3\sigma(\gamma, 3n) + \ldots \quad (2)$$

which is independent of problems of neutron multiplicity sorting. The contributions to this total cross section from the cross sections for $(\gamma, 1n)$, $(\gamma, 2n)$, and $(\gamma, 3n)$ partial reactions are determined (evaluated) with the aid of the results of calculations performed within the combined model of photonuclear reactions [8, 9]. The evaluated cross sections that satisfy relations consistent with basic principles of this model and which obey the data-reliability criteria are taken in the form

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

and the input experimental neutron-production cross section is obtained as a result in the sum in (2). In [1], this approach was used to evaluate cross sections for $(\gamma, 1n)$, $(\gamma, 2n)$, and $(\gamma, 3n)$ partial reactions and for the total photoneutron reaction

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

whose cross section in the case of medium-mass and heavy nuclei (for which proton-reaction cross sections are small) provide a good approximation of the cross section for total photoabsorption on the isotopes ^{188,189}Os.

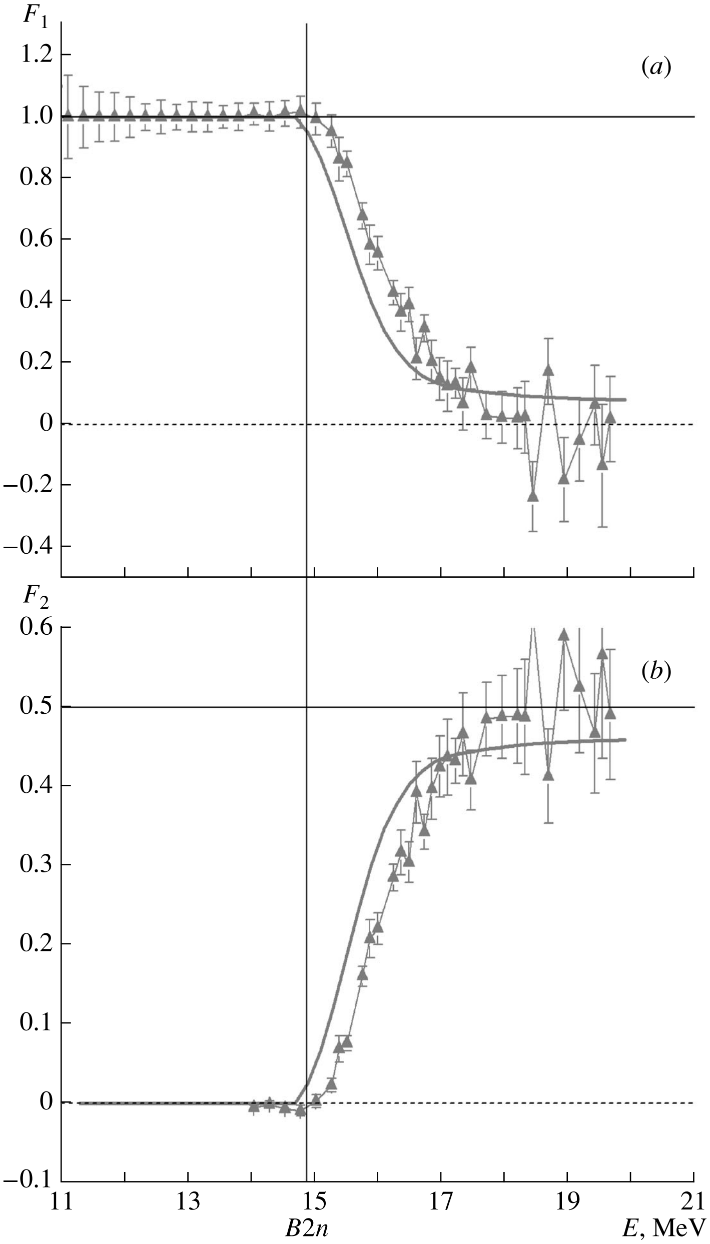

Fig. 2. Comparison (for $i = 1$ in Fig. 2a and for $i = 2$ in Fig. 2b) of the transition multiplicity functions F_i^{expt} obtained from experimental data reported in [2] (triangles) with the transition multiplicity functions F_i^{theor} obtained on the basis of the results of theoretical calculations performed in [8, 9] (lines) for the isotope ^{186}Os.

In the present study, we apply the aforementioned approach to analyzing the reliability of experimental data on the cross sections for photoneutron reactions on the isotopes ^{186,190,192}Os, obtain new data for these nuclei on the basis of the experimental–theoretical approach, and discuss the similarities of and the distinctions between the photodisintegration processes on all of the five osmium isotopes listed above.

2. MATCHING NEUTRON-PRODUCTION CROSS SECTIONS $\sigma(\gamma, xn)$ WITH THE RESULTS OF THEORETICAL CALCULATIONS

In the studies of our group that were performed earlier and which were reported in [3–7, 10, 11], we analyzed a large amount of data on cross sections for total and partial photoneutron reactions. The majority of these data came from experiments performed in beams of quasimonoenergetic photons from annihilation processes in Saclay (France) and Livermore

Table 1. Centers of gravity $E^{\text{c.g.}}$ and integrated cross sections σ^{int} for the neutron-production reaction $^{186,190,192}\text{Os}(\gamma, xn)$

	$E^{\text{c.g.}}$, MeV	σ^{int}, MeV mb	$E^{\text{c.g.}}$, MeV	σ^{int}, MeV mb	$E^{\text{c.g.}}$, MeV	σ^{int}, MeV mb
^{186}Os						
Energy region	$E^{\text{int}} = B2n = 14.9$ MeV*		$E^{\text{int}} = 20.0$ MeV*			
Experiment [2]	13.21	1302.0 ± 14.1	15.13	2833.8 ± 27.8		
Theory—original [8, 9]	13.07	1398.6 ± 37.6	14.99	2812.6 ± 51.0		
Theory—corrected	13.18	1292.5 ± 35.2	15.22	2820.1 ± 51.1		
^{190}Os						
Energy region	$E^{\text{int}} = B2n = 13.7$ MeV		$E^{\text{int}} = B3n = 21.7$ MeV		$E^{\text{int}} = 31.0$ MeV	
Experiment [2]	12.06	1178.1 ± 4.5	15.17	3840.3 ± 17.4	16.90	4623.7 ± 55.1
Theory—original [8, 9]	11.95	1172.9 ± 27.5	15.16	3771.0 ± 52.8	17.35	4780.0 ± 55.5
Theory—corrected	12.01	1203.6 ± 28.7	15.17	3840.3 ± 55.2	17.41	4905.0 ± 58.1
^{192}Os						
Energy region	$E^{\text{int}} = B2n = 13.3$ MeV		$E^{\text{int}} = B3n = 21.1$ MeV		$E^{\text{int}} = 31.0$ MeV	
Experiment [2]	11.72	959.6 ± 4.1	15.06	3924.2 ± 17.1	16.94	4892.0 ± 63.4
Theory—original [8, 9]	11.82	1021.3 ± 24.6	15.13	3943.2 ± 57.3	17.32	5062.8 ± 60.3
Theory—corrected	11.82	1021.3 ± 24.6	15.13	3943.2 ± 57.3	17.32	5062.8 ± 60.3

* Integration is performed over the common energy region of $E > 11.1$ MeV.

(USA) and based on the method of neutron multiplicity sorting. We found that the systematic discrepancies between the cross sections for $(\gamma, 1n)$, $(\gamma, 2n)$, and $(\gamma, 3n)$ partial reactions from the different experiments reach about 60%, but that the discrepancy between the cross sections for the (γ, xn) neutron-production reaction is as small as about 12%.

In view of this, the experimental—theoretical approach to evaluating cross sections for partial photoneutron reactions that was proposed in [3, 4] is based on employing experimental data on precisely the (γ, xn) cross section, which is first of all independent of problems associated with neutron multiplicity sorting and which is rather well described on the basis of the combined photonuclear-reaction model [8, 9]. The situation is further improved upon slightly correcting theoretical cross sections. For the isotopes ^{188,189}Os, this correction included [1] a multiplication by the factors of 1.14 and 1.05, respectively, and the corresponding shifts of 0.30 and 0.45 MeV toward higher energies. In the present study, we only shifted the theoretical cross sections by 0.50 MeV toward higher energies in the case of the isotope ^{186}Os and multiplied the theoretical cross sections by the factor 1.02 in the case of the isotope ^{190}Os. For the isotope ^{192}Os, agreement between experimental and theoretical cross sections was so good that no correction was needed. The cross sections employed for the (γ, xn) reactions on the isotopes ^{186,190}Os in the evaluation procedure on the basis of our experimental—theoretical method are on display in Fig. 1, while the respective integrated cross sections are given in Table 1. One can clearly see how an additional correction improves agreement between the experimental and theoretical cross sections for the neutron-production reaction.

On the basis of the corrected (in the case of the isotopes ^{186,190}Os) or input (in the case of the isotope ^{192}Os) calculated data, the multiplicity transition functions $F_i^{\text{theor}}(1)$ were determined and were used thereupon to obtain the evaluated cross sections (3) for partial reactions.

3. TRANSITION MULTIPLICITY FUNCTIONS F_i FOR NEUTRONS AS OBJECTIVE CRITERIA OF RELIABILITY OF EXPERIMENTAL DATA

In Figs. 2–6, the behavior of the transition multiplicity functions for neutrons, F_i^{theor}, versus energy according to calculations based on the combined photonuclear-reaction model proposed in [8, 9] is contrasted against the energy dependences of the

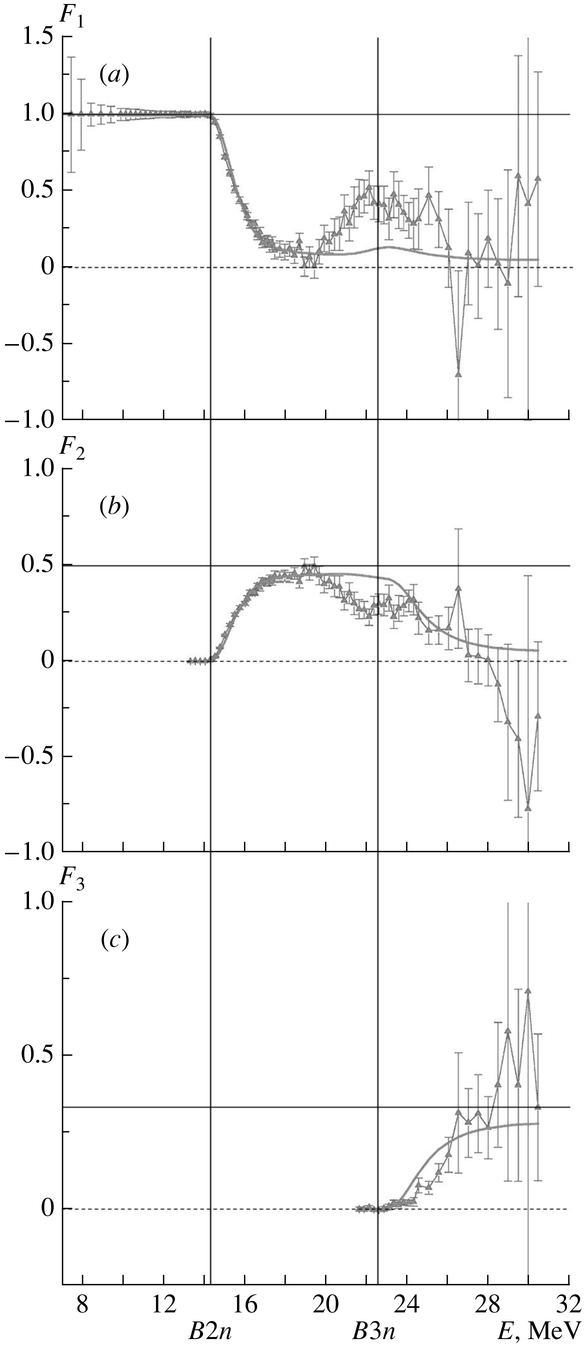

Fig. 3. Comparison of the transition multiplicity functions F_i^{expt} obtained on the basis of experimental data reported in [2] (triangles) with the transition multiplicity functions F_i^{theor} deduced from the theoretical calculations in [8, 9] (lines) for the isotope ^{188}Os at (*a*) $i = 1$, (*b*) $i = 2$, and (*c*) $i = 3$.

functions F_i^{expt} obtained from data reported in [1]. This comparison is illustrated for all of three osmium isotopes discussed in the present articles (^{186,190,192}Os) and for the isotopes ^{188,189}Os, which were studied earlier.

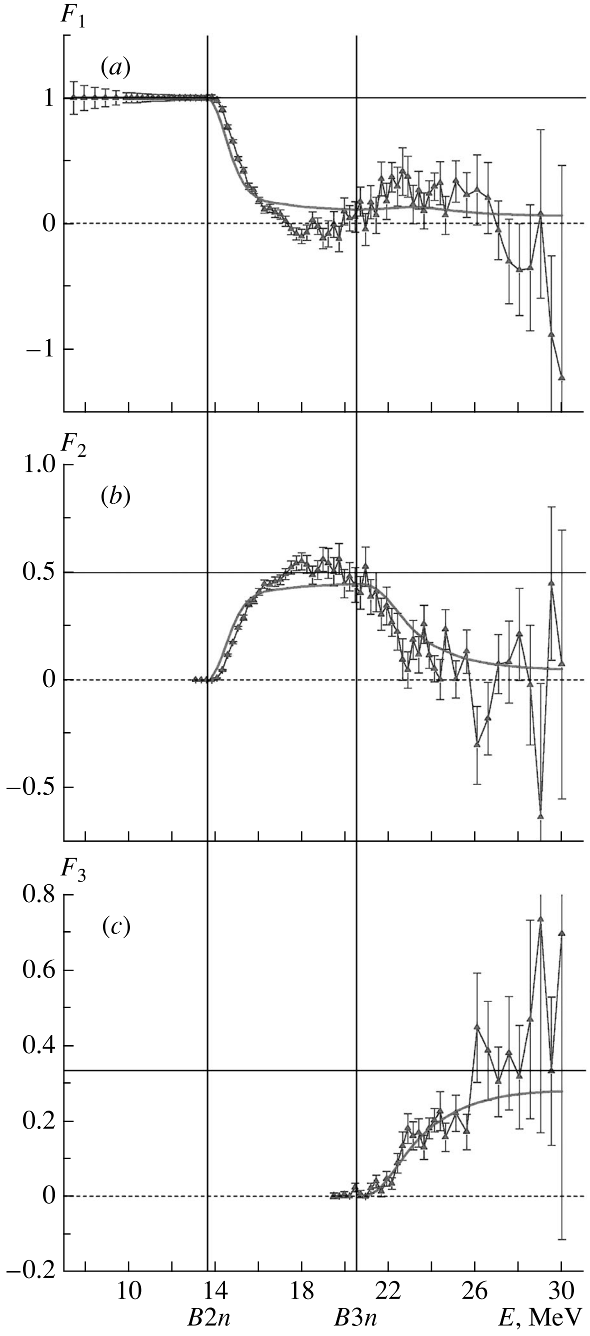

Fig. 4. As in Fig. 3, but for the isotope ^{189}Os.

The data on display give a clear idea of special features of the functions F_i^{expt}, exhibiting the presence of significant systematic errors in the cross sections for partial photoneutron reactions, and this arouses a doubt about the reliability of experimental data.

By way of example, we indicate that, for the isotope ^{186}Os, the function F_1^{expt} at energy values in excess of about 17.5 MeV exhibits negative values (Fig. 2*a*), which correlate with the values of the function F_2^{expt}

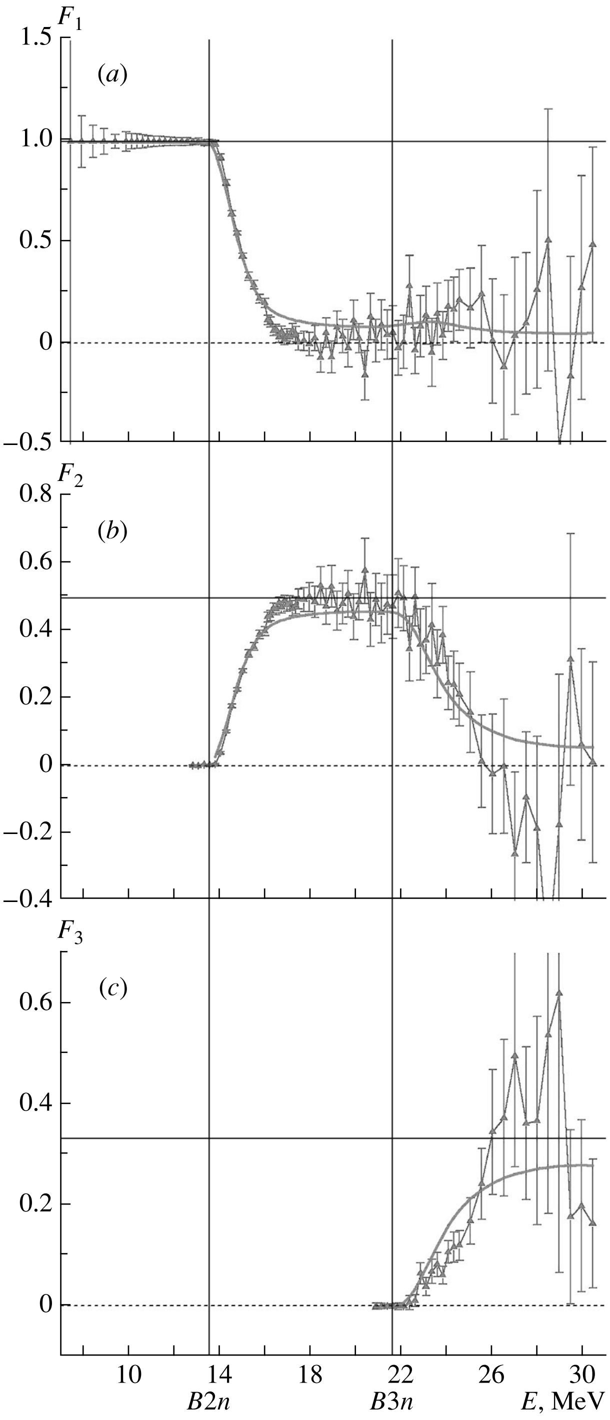

Fig. 5. As in Fig. 3, but for the isotope ^{190}Os.

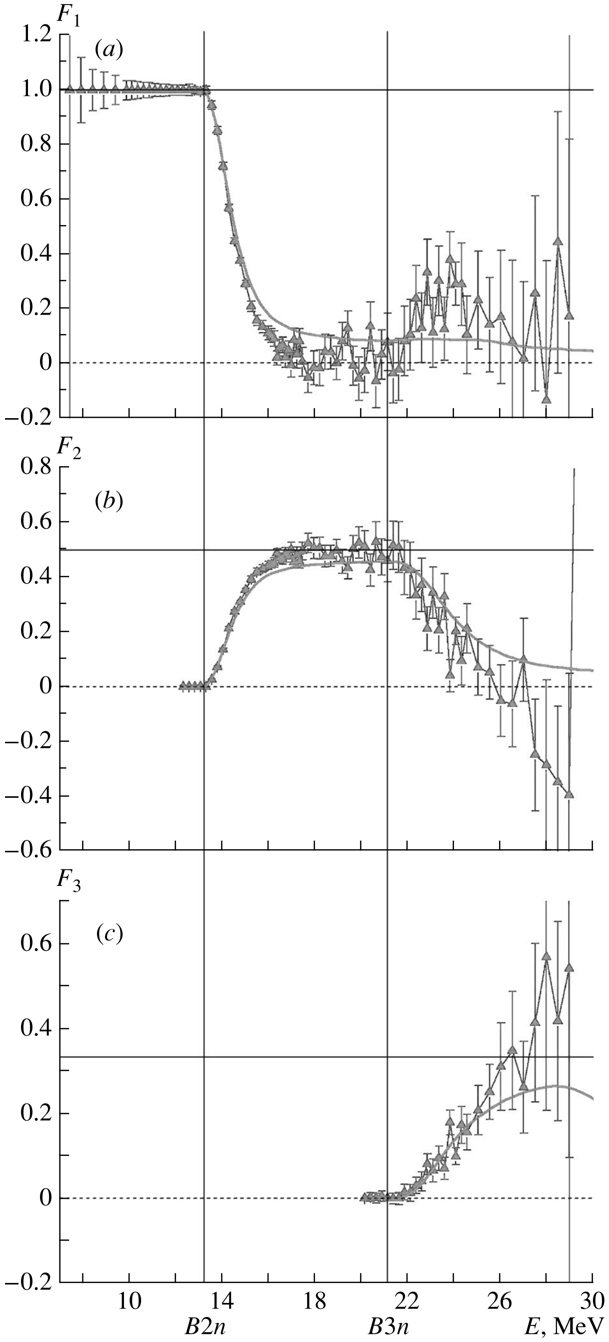

Fig. 6. As in Fig. 3, but for the isotope ^{192}Os.

(Fig. 2*b*) that exceed the physically allowed [according to the definition in (1)] limit of 0.50.

Further, similar correlations between the regions where $F_1^{\rm expt} < 0$ and $F_2^{\rm expt} > 0.50$ in the energy range between about 18 and 22 MeV are observed for the isotopes ^{189,190,192}Os (see Figs. 4–6).

In the case of the isotope ^{188}Os (Fig. 3), there are virtually no unreliable values in the regions of $F_1^{\rm expt} < 0$ and $F_2^{\rm expt} > 0.50$, but antiphase deviations of the functions $F_1^{\rm expt}$ and $F_2^{\rm expt}$ from the theoretical functions $F_1^{\rm theor}$ and $F_2^{\rm theor}$, respectively, are quite distinct.

For the isotopes ^{188,189,190,192}Os, the function F_3 in the energy range between about 26 and 30 MeV takes values from about 0.6 to 0.8, which are substantially greater than the physically allowed [according to the definition in (1)] limit of 0.33.

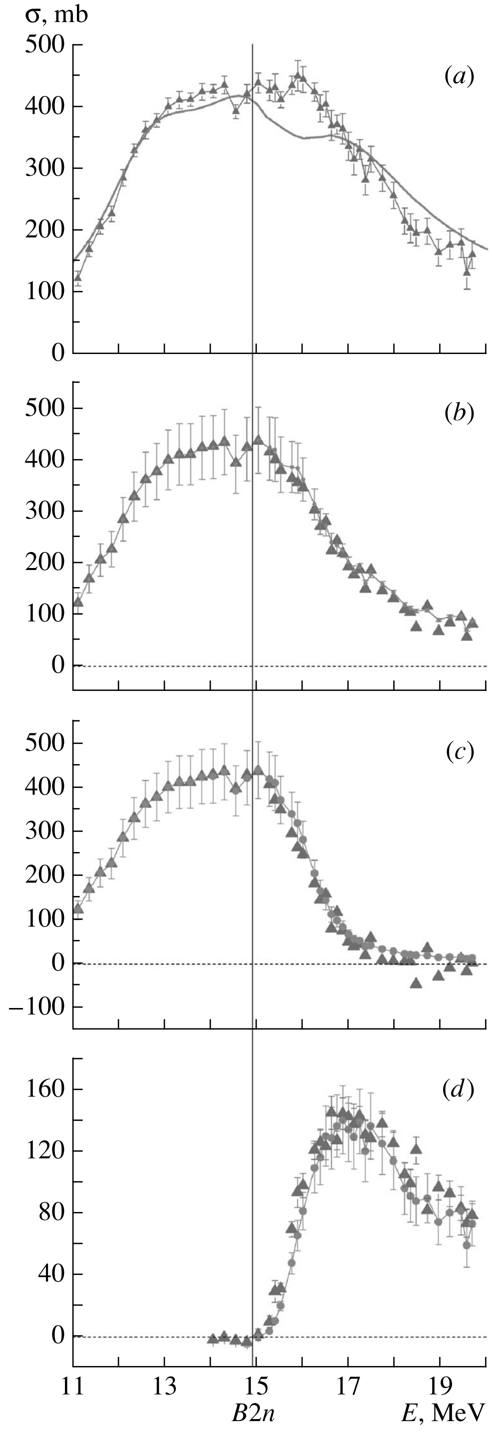

Fig. 7. Cross sections for the photodisintegration of the isotope ^{186}Os that were obtained on the basis of our experimental–theoretical approach to evaluating cross sections for photoneutron reactions. The results are given for the following reactions: (a) (γ, xn), (b) (γ, sn), (c) $(\gamma, 1n)$, and (d) $(\gamma, 2n)$. Here and in Figs. 8 and 9, the triangles represent the experimental cross sections.

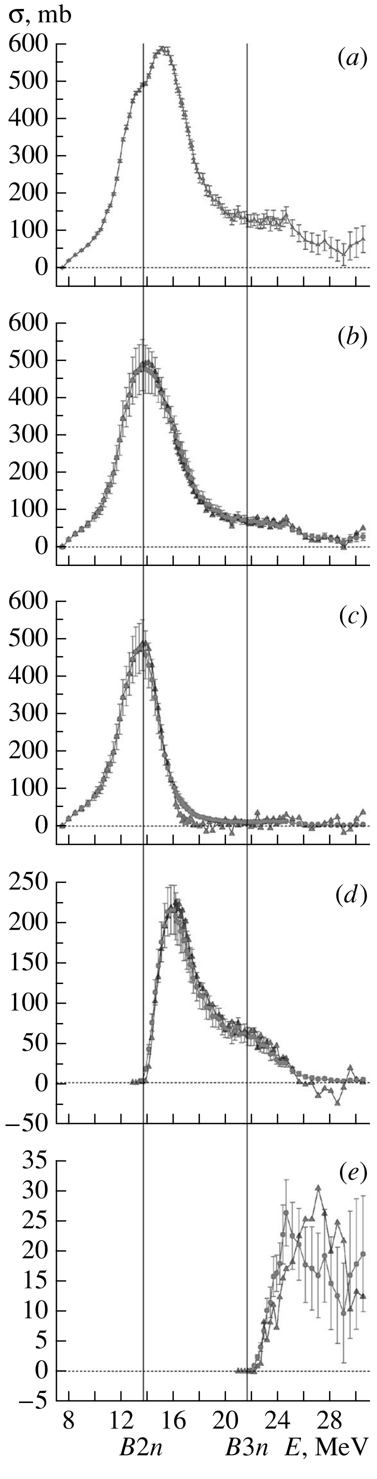

Fig. 8. Cross sections for the photodisintegration of the isotope ^{190}Os that were obtained on the basis of our experimental–theoretical approach to evaluating cross sections for partial photoneutron reactions. The results are given for the following reactions: (a) (γ, xn), (b) (γ, sn), (c) $(\gamma, 1n)$, (d) $(\gamma, 2n)$, and (e) $(\gamma, 3n)$.

The data on the functions F_i in Figs. 2–6 indicate that an unjustifiable redistribution of substantial fractions of neutrons between the $1n$, $2n$, and $3n$ channels for individual osmium isotopes manifests itself differently in the experimental data. These manifestations are quite peculiar in energy regions above

$B3n$, where all three possible partial reactions compete.

In the case of the isotopes ^{188,190,192}Os, the function $F_1^{\rm expt}$ (see Figs. 3, 5, and 6) lies by and large near the values of $F_1^{\rm theor}$ and, within the errors, does not take negative values (with the exception of one value at an energy of about 26.5 MeV for the isotope ^{188}Os). At the same time, the values of the function $F_2^{\rm expt}$ for these isotopes are negative (with the exception of the value at an energy of about 27 MeV for ^{192}Os). In the case of this correlation, values in the region of $F_3^{\rm expt} > 0.33$ are indicative of unjustifiably removing part of neutrons from the $2n$ channel and associating them with the $3n$ channel.

At the same time, the function $F_1^{\rm expt}$ for the isotope ^{189}Os (see Fig. 4) at energies higher than about 24 MeV has negative values, while the function $F_2^{\rm expt}$ for this isotope does not have negative values within the errors (with the exception of the value at an energy of about 26 MeV). For this correlation, values in the region of $F_3^{\rm expt} > 0.33$ are indicative of unjustifiably moving part of neutrons from the $1n$ to the $3n$ channel.

The above correlations between values in the regions of $F_1^{\rm expt} < 0$ and $F_2^{\rm expt} > 0.50$ at energies from about 18 to 22 MeV for the isotopes ^{186,190,192}Os and the fact that there are no such correlations for the isotope ^{189}Os are indicative of different and unreliable distributions of neutrons between the $1n$ and $2n$ channels.

4. CROSS SECTIONS EVALUATED FOR PARTIAL PHOTONEUTRON REACTIONS ON THE BASIS OF THE EXPERIMENTAL–THEORETICAL APPROACH

The cross sections evaluated for the $(\gamma, 1n)$, $(\gamma, 2n)$, $(\gamma, 3n)$, and (γ, sn) reactions on ^{186,190,192}Os nuclei on the basis of the experimental–theoretical approach by using Eq. (3) are presented in Figs. 7–9 along with the corresponding experimental cross sections for the (γ, xn) reaction.

The integrated features that were calculated for the cross sections being considered over the whole range of energies under study are given in Table 2 along with the features of the isotopes ^{188,189}Os, which were studied earlier in [1]. For the isotopes ^{190,192}Os {as well as for the isotopes ^{188,189}Os (see [1])}, Table 3 gives the integrated cross sections calculated for energies in excess of $B3n$.

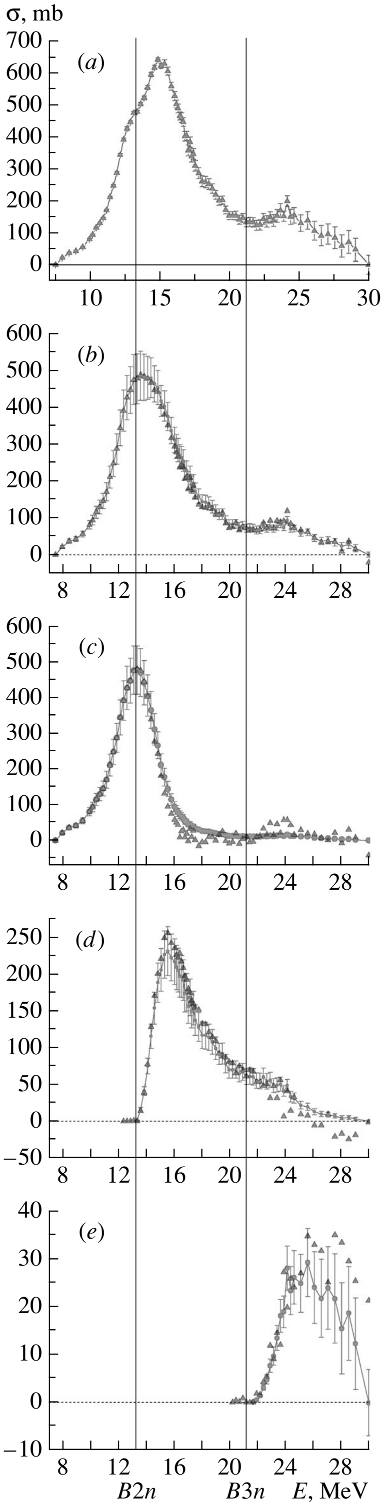

Fig. 9. As in Fig. 8, but for the isotope ^{192}Os.

4.1. Photodisintegration of the Isotope ^{186}Os

It was indicated above that, at energies higher than a value of about 17.5 MeV, negative values of the function $F_1^{\rm expt}$ correlate with values of the function

Table 2. Integrated cross sections $\sigma^{\rm int}$ of the evaluated cross sections for total and partial photoneutron reactions on osmium isotopes along with experimental data reported in [2]

Reaction	$\sigma^{\rm int}$, MeV mb	
	Evaluated data	Experimental data
	^{186}Os ($E^{\rm int} = 20.0$ MeV)	
(γ, xn)	$2810.8 \pm 22.9^*$	2810.8 ± 22.9
(γ, sn)	2389.3 ± 57.5	2345.0 ± 24.2
$(\gamma, 1n)$	1967.9 ± 57.5	1879.2 ± 23.1
$(\gamma, 2n)$	472.8 ± 10.3	465.8 ± 7.2
	^{188}Os ($E^{\rm int} = 31.0$ MeV) [1]	
(γ, xn)	$4755.0 \pm 58.9^*$	4755.0 ± 58.9
(γ, sn)	3521.4 ± 74.5	3634.1 ± 58.5
$(\gamma, 1n)$	2402.5 ± 62.8	2633.6 ± 53.5
$(\gamma, 2n)$	1004.1 ± 36.6	880.1 ± 22.7
$(\gamma, 3n)$	114.7 ± 16.8	120.4 ± 6.7
	^{189}Os ($E^{\rm int} = 31.0$ MeV) [1]	
(γ, xn)	$4715.0 \pm 47.5^*$	4715.0 ± 47.5
(γ, sn)	3341.6 ± 46.6	3310.3 ± 54.1
$(\gamma, 1n)$	2133.0 ± 39.9	2109.7 ± 46.6
$(\gamma, 2n)$	1043.4 ± 20.9	996.1 ± 25.9
$(\gamma, 3n)$	165.2 ± 11.8	205.6 ± 9.3
	^{190}Os ($E^{\rm int} = 31.0$ MeV)	
(γ, xn)	$4623.7 \pm 55.1^*$	4623.7 ± 55.1
(γ, sn)	3276.7 ± 62.5	3251.4 ± 63.2
$(\gamma, 1n)$	2068.1 ± 55.4	2024.9 ± 51.5
$(\gamma, 2n)$	1080.6 ± 25.3	1081.3 ± 29.3
$(\gamma, 3n)$	138.5 ± 14.3	145.4 ± 9.7
	^{192}Os ($E^{\rm int} = 31.0$ MeV)	
(γ, xn)	$4892.0 \pm 63.4^*$	4892.0 ± 63.4
(γ, sn)	3392.7 ± 63.4	3305.5 ± 62.5
$(\gamma, 1n)$	2032.8 ± 54.5	1903.1 ± 54.2
$(\gamma, 2n)$	1221.8 ± 28.4	1199.7 ± 28.4
$(\gamma, 3n)$	138.0 ± 15.3	202.8 ± 12.2

* Experimental cross section presented in [2] and used as an input in the evaluation procedure.

Table 3. Integrated cross sections $\sigma^{\rm int}$ ($E^{\rm int} > B3n$) of evaluated cross sections for the $(\gamma, 1n)$ and $(\gamma, 2n)$ partial reactions on ^{190,192}Os nuclei along with experimental data from [2]

Reaction	$\sigma^{\rm int}$, MeV mb	
	Evaluated data	Experimental data
	^{188}Os ($E^{\rm int} = 22.5$–31.0 MeV)	
$(\gamma, 1n)$	69.3	231.1
$(\gamma, 2n)$	179.2	98.2
$(\gamma, 3n)$	114.7	120.4
	^{189}Os ($E^{\rm int} = 20.2$–31.0 MeV)	
$(\gamma, 1n)$	103.3	115.1
$(\gamma, 2n)$	210.9	147.6
$(\gamma, 3n)$	165.2	205.6
	^{190}Os ($E^{\rm int} = 21.7$–31.0 MeV)	
$(\gamma, 1n)$	62.7	93.5
$(\gamma, 2n)$	178.5	126.8
$(\gamma, 3n)$	138.5	145.4
	^{192}Os ($E^{\rm int} = 21.1$–31 MeV)	
$(\gamma, 1n)$	76.1	121.7
$(\gamma, 2n)$	238.0	128.8
$(\gamma, 3n)$	138.0	202.8

$F_2^{\rm expt}$ greater than 0.50. This implies an unreliable transfer of part of the neutrons from the $1n$ to the $2n$ channel, with the result that the $(\gamma, 1n)$ cross section decreases to such an extent that it develops physically forbidden negative values, while the $(\gamma, 2n)$ cross section grows accordingly up to values leading to the appearance of physically unjustifiable values of the function $F_2^{\rm expt}$. The redistribution in question is fully confirmed by a comparison of the experimental and evaluated reaction cross sections in Fig. 7. Table 4 gives the respective integrated cross sections that were calculated up to 20 MeV, which was the maximum energy under study, and for the range of 17.5–20 MeV, where the discrepancies were maximal.

4.2. Photodisintegration of the Isotopes ^{188,189}Os

On the basis of the data presented in Tables 2 and 3 for the isotopes ^{188,189}Os and obtained earlier in [1], we drew the following conclusions concerning special features of the photodisintegration of these isotopes: for the isotope ^{188}Os, the results of separating multiplicity-one neutrons were close to the predictions of the model proposed in [8, 9], while, for the isotope ^{189}Os, a similar statement was true for multiplicity-two neutrons. The results of sorting neutrons in the case of competing multiplicities (two versus three in the case of ^{188}Os and one versus three in the case of ^{189}Os) in the experiment reported in [2] differ substantially from model predictions [1].

Table 4. Centers of gravity $E^{\text{c.g.}}$ of evaluated cross sections σ^{int} for total and partial photoneutron reactions on ^{186}Os nuclei and integrated cross sections σ^{int} of them along with experimental data [2]

Reaction	Evaluated data		Experimental data	
	$E^{\text{c.g.}}$, MeV	σ^{int}, MeV mb	$E^{\text{c.g.}}$, MeV	σ^{int}, MeV mb
	$E^{\text{int}} = 20.0$ MeV			
$(\gamma, xn)^*$	15.2	2810.8 ± 22.9	15.2	2810.8 ± 22.9
(γ, sn)	14.7	2389.3 ± 57.5	14.7	2345.0 ± 24.2
$(\gamma, 1n)$	14.0	1967.9 ± 57.5	14.1	1879.2 ± 23.1
$(\gamma, 2n)$	17.6	472.8 ± 10.3	17.6	465.8 ± 7.2
	$E^{\text{int}} = 17.5$–20.0 MeV			
$(\gamma, 1n)$		44.0 ± 2.6		-3.9 ± 14.8
$(\gamma, 2n)$		194.8 ± 11.1		218.7 ± 5.5

* Experimental cross section obtained in [2] and used as an input in the evaluation procedure.

4.3. Photodisdisintegration of the Isotopes ^{190,192}Os

On the basis of the data presented in Figs. 5 and 6 and in Tables 2 and 3, the photodisintegration of the two isotopes was studied experimentally in [2] with similar systematic errors. In either case, sizable fractions of neutrons were unjustifiably taken from the $1n$ to the $2n$ channel at energies below $B3n$ and from the $2n$ channel to the $1n$ and $3n$ channels at high energies.

At the same time, the data in Table 3 indicate that, for both isotopes being discussed, there are substantial distinctions between the unjustifiable redistribution of neutrons between different channels.

In the case of the isotope ^{190}Os (see Fig. 8), a discrepancy of 37% between the experimental and evaluated integrated cross sections (126.8 versus 178.5 MeV mb) for the $(\gamma, 2n)$ reaction is due primarily to a discrepancy of 30.8% (93.5 versus 62.7 MeV mb) between the analogous data on the cross section for the $(\gamma, 1n)$ reaction. At the same time, the discrepancy between the experimental and evaluated data on the $(\gamma, 3n)$ cross section is moderately small: 6.9% (145.4 versus 138.5 MeV mb). This means that, for the most part, neutrons were unjustifiably moved from the $2n$ to the $1n$ channel, but that, in the $3n$ channel, neutrons were identified by and large correctly (the errors were relatively small).

In the case of the isotope ^{192}Os (see Fig. 9), the situation is substantially different. A discrepancy of 101.2% (128.8 versus 238.0 MeV mb) between the experimental and estimated integrated cross sections for the $(\gamma, 2n)$ reaction is comparable with the sum of the commensurate discrepancies between the analogous data on the cross section for the $(\gamma, 1n)$ reaction (45.6%: 121.7 versus 76.1 MeV mb) and the cross section for the $(\gamma, 3n)$ reaction (64.8%: 202.8 versus 138.0 MeV mb). This means that the inclusion of neutrons removed from the $2n$ channel in the $1n$ and $3n$ channels was almost equally unjustifiable (in all of the three channels, large errors marred the identification of neutrons).

Summarizing the data quoted above, we emphasize that, for all of the isotopes ^{186,188,189,190,192}Os studied here, the evaluated partial-photoneutron-reaction cross sections satisfying the data-reliability criteria introduced above differ substantially from the experimental cross sections, which do not satisfy these criteria. The distinctions between the evaluated and experimental cross sections for partial photoneutron reactions have an individual character that stems from special features of the energy spectra of emitted neutrons.

5. SYSTEMATIC ERRORS IN THE METHOD OF NEUTRON MULTIPLICITY SORTING

So a distinct difference in the systematic errors of the experimental neutron-multiplicity-sorting method used in [2] to study the photodisintegration of isotopes differing by one to two neutrons confirms the conclusions drawn in employing the experimental–theoretical method for evaluating cross sections for partial photoneutron reactions [1, 3–7, 10, 11] on the reasons for the unjustifiable and unreliable redistribution of neutrons between channels characterized by different multiplicities. Significant systematic errors in determining the multiplicity of experimentally detected neutrons on the basis of their measured kinetic energies stemmed from the circumstance that the relation between these features of neutrons proved to be much more complicated than a relatively simple, unambiguous, and direct relation assumed within the method used.

The method used in [2] to perform neutron multiplicity sorting relied on the assumption that the neutron from a $(\gamma, 1n)$ reaction has an energy much higher than the energies of the two neutrons from the respective $(\gamma, 2n)$ reaction. However, experimental and theoretical investigations of the spectra of neutrons from $(\gamma, 1n)$, $(\gamma, 2n)$, and $(\gamma, 3n)$ reactions indicate [6] that this is not so in many cases. Although neutrons of ever higher energy appear upon going over to energies above the threshold for the next multinucleon reaction, the main maximum in the spectrum of neutrons from reactions yielding different numbers of neutrons undergoes virtually no change in position on the energy scale (0.5–1.0 MeV).

This situation creates additional problems in neutron multiplicity sorting on the basis of data on neutron kinetic energies. The proximity of kinetic energies of neutrons that have different multiplicities leads to large systematic errors in partial-reaction cross sections determined experimentally. It is these systematic errors that are predominantly responsible for the distinctions between the experimental and evaluated reaction cross sections.

6. CONCLUSIONS

The investigations reported in the present article make it possible to draw conclusions on special features of the photodisintegration of the isotopes ^{186,188,189,190,192}Os.

Experimental data obtained in [2] on the cross sections for $(\gamma, 1n)$, $(\gamma, 2n)$, and $(\gamma, 3n)$ partial photoneutron reactions by the method of photoneutron multiplicity sorting have sizable systematic errors and do not satisfy the proposed criteria of data reliability. Because of unjustifiable redistributions of significant numbers of neutrons between channels characterized by different multiplicities, the energy dependences of the functions F_i^{expt} specially introduced as the ratios of the cross sections for partial reactions to the neutron-production cross section may assume values exceeding physically admissible upper limits (0.50 and 0.33 for $i = 2$ and 3, respectively) or physically forbidden negative values. This is due [6] to the proximity of kinetic energies of neutrons from different partial reactions, which complicates substantially the determination of the neutron multiplicity and which renders incorrect the neutron-multiplicity-sorting procedure used in [2].

On the basis of the experimental–theoretical method described above, we have evaluated the cross sections both for the $(\gamma, 1n)$, $(\gamma, 2n)$, and $(\gamma, 3n)$ partial reactions and for the (γ, sn) total reaction on the isotopes ^{186,188,189,190,192}Os studied here. We have shown that, for each isotope, the evaluated cross sections for partial photoneutron reactions differ substantially from the experimental cross sections. The distinctions between them have an individual character that is due to special features of the energy spectra of emitted neutrons.

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