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# New Data on the Photodisintegration of $^{140, 142}$Ce and $^{153}$Eu Nuclei

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**Abstract**—Experimental data for $^{140, 142}$Ce and $^{153}$Eu nuclei are analyzed jointly using the cross sections for total and partial photoneutron reactions obtained with quasimonoenergy photon beams formed during the annihilation of relativistic positrons. The results from an experiment performed on a bremsstrahlung beam are also used for such an analysis for the $^{153}$Eu nucleus. Well-known systemic discrepancies between the results of different experiments are analyzed using the objective physical criteria of data reliability, and ways of allowing for them are considered. New data on the cross sections of (γ, 1*n*) and (γ, 2*n*) reactions for $^{140, 142}$Ce nuclei, on the cross section of (γ, 3*n*) reaction for $^{153}$Eu nucleus, and on the cross section of total photoneutron reaction for all three nuclei were obtained additionally the cross sections of partial reactions that satisfy the established criteria of reliability. It was shown that substantial deviations of the experimental reaction cross sections from those evaluated are due to an unreliable sorting of neutrons between the channels with a multiplicity of 1, 2 due to the abovementioned systematic uncertainties.

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## INTRODUCTION

Reliable and accurate information on the cross sections of total and partial photoneutron reactions is widely used in fundamental and applied research to solve a number of the most important problems of electromagnetic interactions in the field of giant dipole resonance (GDR). Above all, those are the relationship between direct and statistical processes in the formation and decay of highly excited nuclear states, determination of the role of various components in the formation of isospin GDR splitting, competition of various types of transitions that form components of the GDR configuration splitting, and much else. In addition, data on cross sections of partial photoneutron reactions are widely used in different fields of science and technology (e.g., nuclear physics and nuclear energy, radiation disciplines of chemistry, geology, and medicine).

The data from systematic analysis [1–3] of the cross sections of total and partial photoneutron reactions allow one to establish that there are significant discrepancies between the results from different experiments. Different ways of obtaining information on reaction cross sections result in noticeable (on average, ~10%) systemic discrepancies in the results already at determining the cross section for the photoneutron yield reaction σ(γ, *xn*):

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

Discrepancies between the cross sections of partial reactions (γ, 1*n*), (γ, 2*n*), (γ, 3*n*), ... are even greater. They far exceed the statistical uncertainties of experiments and can be as high as 60–100%.

Most of the experiments to determine cross sections of partial photoneutron reactions have been performed on beams of quasimonoenergetic annihilation photons at Livermore (United States) and Saclay (France) using different methods of photoneutron sorting multiplicity that are based on the assumption of a direct connection of this multiplicity with the average energy of neutrons [4, 5]. It was shown in [3, 6–12] that the systematic discrepancies found between the results from such experiments are due to certain disadvantages of the methods used for photoneutron multiplicity sorting. The ratios of reaction cross sections σ(γ, 1*n*) and σ(γ, 2*n*) obtained at both laboratories and depending on the features of the methods used differ greatly from the ratios of reaction cross sections σ(γ, *xn*), which are rather independent of these features.

The reliability of the experimental data was analyzed and reliable cross sections for partial and total photoneutron reactions

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

were evaluated for $^{140, 142}$Ce and $^{153}$Eu nuclei in this work.

Interest in data on Ce isotopes is due to the ratio of the cross sections for the (γ, 1*n*) and (γ, 2*n*) reactions, which is very interesting and not typical for the nuclei of this region of A values obtained using the method for neutron multiplicity sorting at Saclay (France) [13]. The integral cross sections for the reactions (γ, 1*n*) and (γ, 2*n*) are equal to 1941 and 457 MeV mb for the $^{140}$Ce isotope, respectively, while they are 1022 and 1186 MeV mb for the $^{142}$Ce isotope [4]. This results in a very uncharacteristic ratio of the integral cross sections of the total photoneutron reaction on $^{140}$Ce and $^{142}$Ce isotopes: 2398 and 2208 MeV mb, respectively; and neutron yield cross sections of 2855 and 3394 MeV · mb. It was established in [13] that the cross section of total photoneutron reaction (2) decreased (from 384 to 332 mb), and the corresponding resonance width grew (from 4.4 to 5.2 MeV) upon moving from the $^{140}$Ce isotope to the $^{142}$Ce isotope. At the same time, it was found that the cross section of the total photoneutron reaction (2) grew (from 281 to 318 mb, respectively), and the corresponding resonance width decreased (from 5.5 to 5.1 MeV) as mass number A grew in the investigated neighboring $^{124, 126, 128, 130}$Te nuclei. Studying the reliability of these discrepancies using the proposed criteria of data reliability is therefore of interest.

The interest in data for $^{153}$Eu nucleus is due to two factors. On the one hand, there are physically forbidden negative values in the experimental (γ, 1*n*) reaction cross section, obtained using the method for neutron multiplicity sorting at Livermore (United States) [14], and there is doubt about the reliability of those. On the other hand, the data on the cross sections for the (γ, *xn*) and (γ, *sn*) reactions published for the $^{153}$Eu nucleus and obtained in an experiment on the bremsstrahlung γ-radiation in Saratov (Russia) [15], provided data on the cross sections for partial reactions and were used to discuss data reliability.

## TRANSITIONAL MULTIPLICITY FUNCTIONS F$_I$ AS OBJECTIVE CRITERIA OF RELIABILITY OF DATA ON THE CROSS SECTIONS OF PARTIAL PHOTONEUTRON REACTIONS

Transitional multiplicity functions

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

were proposed as objective physical criteria of reliability of data on the cross sections of partial photoneutron reactions [16].

Ratios $F_i$ must not have values exceeding those physically permissible by definition (3) 1.00, 0.50, 0.33, ... for $i$ = 1, 2, 3, ..., respectively. The $F_i^{\text{exp}}$ ratios exceeding the specified top limit values indicate physically unreliable neutron distributions between the (γ, 1*n*) and (γ, 2*n*), (γ, 2*n*) and (γ, 3*n*) reactions caused by significant systematic uncertainties in the experimental neutron multiplicity sorting method.

The results from [3, 6–12] also showed that physically forbidden negative values in the reaction cross sections can serve as a criterion for the unreliability of the data: all terms included in relations (3) are reaction cross sections and have an area dimension.

A comparison of partial reactions estimated by experimental and theoretical means, along with the results from research using activation method (as an alternative to the method for neutron multiplicity sorting) showed [17, 18] the reliability of experimental reaction sections can be doubted.

Figure 1 shows the energy dependences of the transitional neutron multiplicity functions ($F_i^{\text{exp}}$ (3) ratios) obtained for $^{140}$Ce and $^{142}$Ce nuclei according to [13], and for the $^{153}$Eu nucleus according to [14, 15], which are compared to the $F_i^{\text{theor}}$ functions [19, 20].

Physically reliable energy dependences of the functions $F_{1,2,3}^{\text{theor}}$, calculated in the CM [19, 20] correspond to definitions (3):

- Up to the *B*2*n* reaction threshold (γ, 2*n*), $F_1^{\text{theor}}$ = 1; after opening channel 2n, it decreases according to the competition between the increase of cross section σ(γ, 2n) and the decrease of cross section σ(γ, 1n), gradually approaching zero.

- Up to the *B*2*n* threshold $F_2^{\text{theor}}$ = 0; after opening channel 2*n*, $F_2^{\text{theor}}$ increases according to the competition between the increase of cross section σ(γ, 2*n*) and the decrease of cross section σ(γ, 1*n*), approaching a value of 0.50 from below, never reaching it. After opening channel 3*n*, it decreases according to the 3σ(γ, 3*n*) contribution in the denominator of ratio (2).

- Up to *B*3*n* threshold $F_3^{\text{theor}}$ = 0 after opening channel 3*n*, $F_3^{\text{theor}}$ increases according to the competition between the increase of cross section σ(γ, 3*n*) and the decrease of cross section σ(γ, 2*n*). It approaches a value 0.33 from below, and never reaches it. After opening channel 4*n*, it decreases according to the 4σ(γ, 4*n*) contribution in the denominator of ratio (3).

It is clearly seen that the reliability of experimental data can be doubted in many energy ranges.

There are no negative $F_i^{\text{exp}}$ values for the $^{140}$Ce nucleus, or values of $F_2^{\text{exp}} > 0.50$. At the same time, the $F_i^{\text{exp}}$ and $F_i^{\text{theor}}$ ratios differ noticeably over the investigated energy ranges, except for those of ~16.5–18 MeV and several values near ~26 MeV that almost coincide. $F_1^{\text{theor}}$ substantially exceeds $F_2^{\text{exp}}$ in the energy range of ~20–25 MeV. At the same time, $F_2^{\text{exp}}$ substantially exceeds $F_2^{\text{theor}}$; the behavior of $F_2^{\text{exp}}$ relative to $F_2^{\text{theor}}$ is virtually a mirror image of the behavior of $F_1^{\text{exp}}$.

There are no negative values of $F_i^{\text{exp}}$ for the $^{142}$Ce nucleus; only four points near the energy of ~20.5 MeV have values of $F_2^{\text{exp}} > 0.50$; at the same time, $F_2^{\text{exp}}$ substantially exceeds $F_2^{\text{theor}}$ in the energy range of ~20–24 MeV.

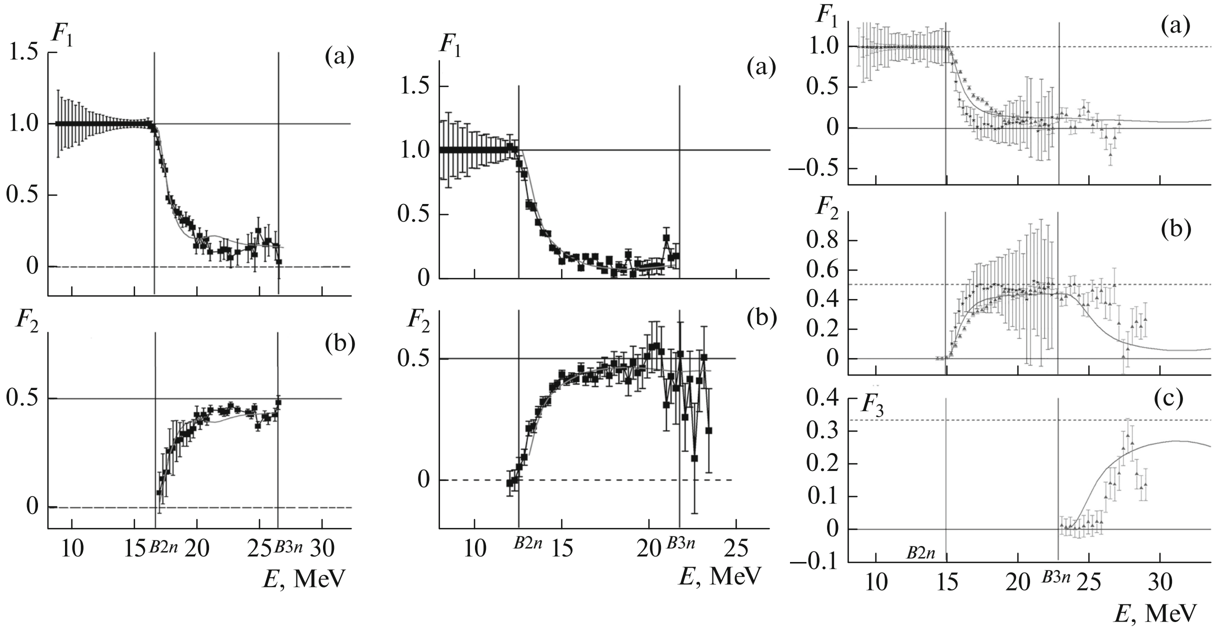


**Fig. 1.** Comparison ((a, b, c) for $i$ = 1, 2, 3) of the transitional multiplicity functions $F_i^{exp}$ obtained from experimental data (squares [13], triangles [14], and stars [15]) with functions $F_i^{theor}$ obtained from the results of theoretical calculations [19, 20] for $^{140}Ce$ (left panel), $^{142}Ce$ (center panel), and $^{153}Eu$ (right panel) nuclei.

Negative $F_1^{exp}$ values for the $^{153}Eu$ nucleus [16] are observed at energies of ~25–27 MeV. Substantial discrepancies between $F_2^{exp}$ [14] and $F_3^{theor}$ are observed in the same region of energies, and in the region of ~27–29 MeV. In general, agreement between $F_i^{exp}$ [14] and $F_i^{theor}$ is observed only in the energy range of ~19–21 MeV; agreement between $F_i^{exp}$ [15] and $F_i^{theor}$ is in this case observed only in the energy range of ~19.5–21.5 MeV.

These features of the energy dependences of $F_i^{exp}$ show that the experimental sorting of neutrons between the partial reactions was in this case not completely reliable. Some of the neutrons from the (γ, 1$n$) reaction were mistakenly identified as neutrons from the (γ, 2$n$) reaction, with the result that the cross section of the first one was unreliably reduced. The second cross section was unreliably increased until the appearence the values for which $F_2^{exp} > 0.50$.

## EXPERIMENTAL-THEORETICAL METHOD FOR EVALUATING THE CROSS SECTIONS OF PARTIAL PHOTONEUTRON REACTIONS

The experimental-theoretical method for evaluation of the cross sections of partial photoneutron reactions was proposed in order to avoid these cross sections depending on the disadvantages of experimental method for neutron multiplicity sorting [16]. The data on reaction cross section $\sigma^{exp}(\gamma, xn)$ (1), which is rather independent of the neutron multiplicity, are used in this approach as initial experimental information, and reactions with different neutron multiplicity are separated using the transitional multiplicity functions, which are calculated using the combined model (CM) of photonuclear reactions [19, 20].

Reliable data on competing reactions (γ, 1$n$), (γ, 2$n$), and (γ, 3$n$) are evaluated as below:

- Reaction cross sections $\sigma^{theor}(\gamma, 1n)$, $\sigma^{theor}(\gamma, 2n)$, and $\sigma^{theor}(\gamma, 3n)$, calculated theoretically in the frame of the CM [19, 20], are combined into cross section $\sigma^{theor}(\gamma, xn)$ of yield reaction (1).

- Transitional functions $F_i^{theor}(E)$ describing the contributions to cross section $\sigma(\gamma, xn)$ of reactions with the formation of $i$ neutrons are calculated for each value of photon energy $E$.

- Evaluated cross sections $\sigma^{est}(\gamma, in)$ of partial reactions are obtained for each value of neutron multiplicity $i$ using the energy dependences of transitional functions $F_i^{theor}(E)$ and experimental data on the cross section for photoneutron yield reaction $\sigma^{exp}(\gamma, xn)$

$$\sigma^{eval}(\gamma, in) = F_i^{theor}\sigma^{exp}(\gamma, xn). \quad (4)$$

This approach means that the competition between partial reactions is described using the CM ratios, and their corresponding sum $\sigma^{eval}(\gamma, xn)$ is equal to $\sigma^{exp}(\gamma, xn)$.

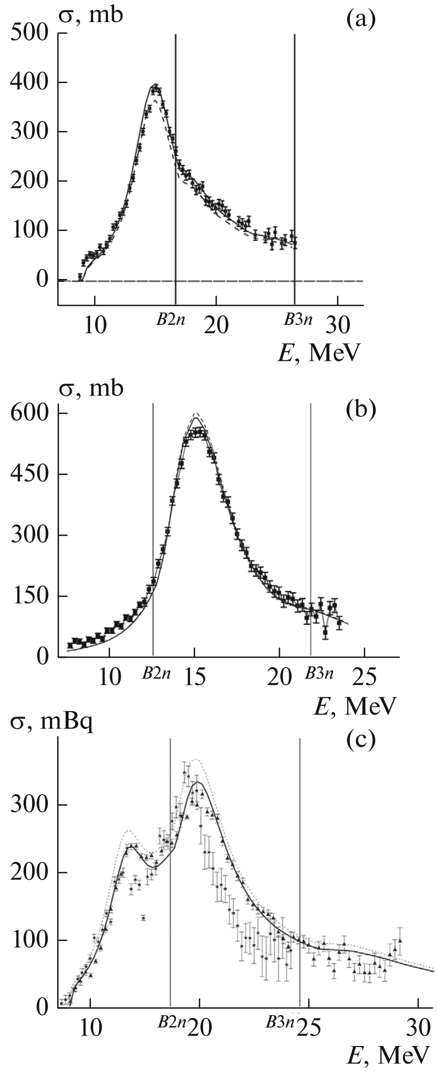


**Fig. 2.** Comparison of the initial (dashed lines) and corrected (solid lines) theoretical [19, 20] cross sections for the photoneutron yield's reactions (γ, *xn*) with experimental data (squares [13], triangles [14], and stars [15]) for $^{140}$Ce (a), $^{142}$Ce (b), and $^{153}$Eu (c).

*Cross Sections of the Photoneutron Yield Reaction (γ, xn)*

The degree of agreement with the experimental data of the photoneutron yield cross sections (γ, *xn*), calculated in the frame of the CM, is of particular importance in the proposed approach for the cross sections of partial photoneutron reactions that satisfy the objective physical criteria of data reliability. The experimental and theoretical neutron yield cross sections are as fully consistent with one another as possible at the preliminary stage of evaluating the partial reaction cross sections.

Experimental cross sections $\sigma^{exp}(\gamma, xn)$ obtained in the experiments whose results are considered here, are compared to theoretical cross sections $\sigma^{theor}(\gamma, xn)$ calculated in the frame of the CM [19, 20] (Fig. 2). It can be seen that the experimental cross sections are in good agreement with the results of calculations for all three nuclei. Despite this, the calculated cross sections were slightly adjusted to achieve the best agreement for each of the three considered nuclei, based on the data on the energy centers of gravity and integral cross sections.

• $\sigma^{theor}(\gamma, xn)$ for the $^{140}$Ce nucleus was shifted to higher energies by 0.01 MeV and multiplied by a factor of 1.087;

• $\sigma^{theor}(\gamma, xn)$ for the $^{140}$Ce nucleus was shifted to lower energies by 0.01 MeV and multiplied by a factor of 0.984;

• $\sigma^{theor}(\gamma, xn)$ for the $^{153}$Eu nucleus was shifted to lower energies by 0.10 MeV and multiplied by a factor of 1.058.

*Evaluated Cross Sections of a Partial Reaction Satisfying Data Reliability Criteria*

The cross sections for the partial reactions (γ, 1*n*), (γ, 2*n*) evaluated using experimental-theoretical method (4) with the $\sigma^{exp}(\gamma, xn)$ sections [13, 14] as initial experimental data are compared to the corresponding experimental data in Figs. 3–5. The integral characteristics of the experimental and evaluated cross sections for the considered partial and total reactions are given in Tables 1–3.

The discrepancies between the evaluated reaction cross sections that satisfy the established validation criteria and the experimental reaction cross sections that do not satisfy these criteria can be described as follows.

*$^{140}$Ce nucleus*

The cross sections for partial reactions (γ, 1*n*) and (γ, 2*n*) evaluated using the experimental-theoretical method (4) with the $\sigma^{exp}(\gamma, xn)$ sections as the initial experimental data [13] are compared to the corresponding experimental data in Fig. 3. The integral characteristics of the experimental and evaluated cross sections for all the considered partial and total reactions are given in Table 1.

The discrepancy between the experimental [13] and evaluated reaction cross sections is negligible in the energy region below the *B*2*n* reaction threshold (γ, 2*n*), where there is no problem of neutron multiplicity sorting: the difference between the integrated cross sections is 0.2% (1556.50 and 1560.05 MeV mb). The data differ noticeably in the high-energy region, where the (γ, 1*n*) and (γ, 2*n*) reactions compete. Thus, $\sigma^{int\text{-}eval}(\gamma, 1n) > \sigma^{int\text{-}exp}(\gamma, 1n)$ by 3.0% (1965.12 and 1941.58 MeV mb) [13] and for $\sigma^{int\text{-}eval}(\gamma, 2n) < \sigma^{int\text{-}exp}(\gamma,$

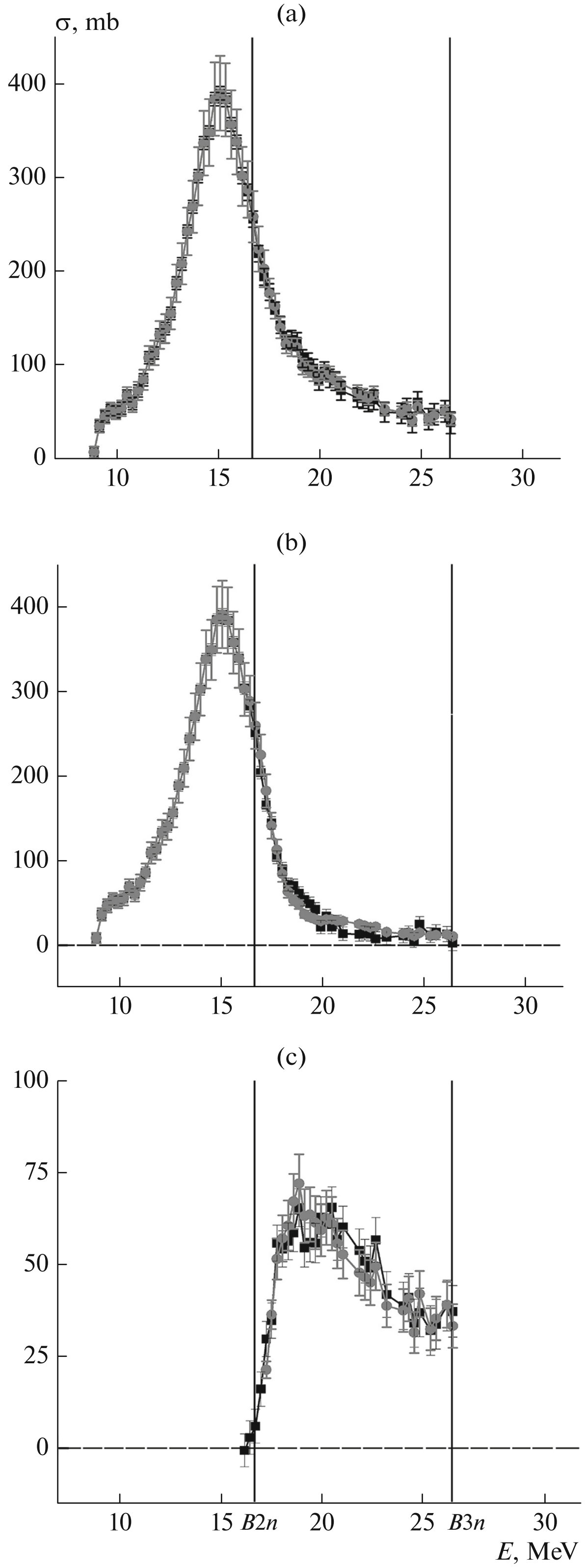


**Fig. 3.** Comparison of evaluated (circles) and experimental (squares [13]) data for the cross sections of total and partial photoneutron reactions on a $^{140}$Ce nucleus: (a) σ(γ, *xn*), (b) σ(γ, s*n*), and (c) σ(γ, 1*n*).

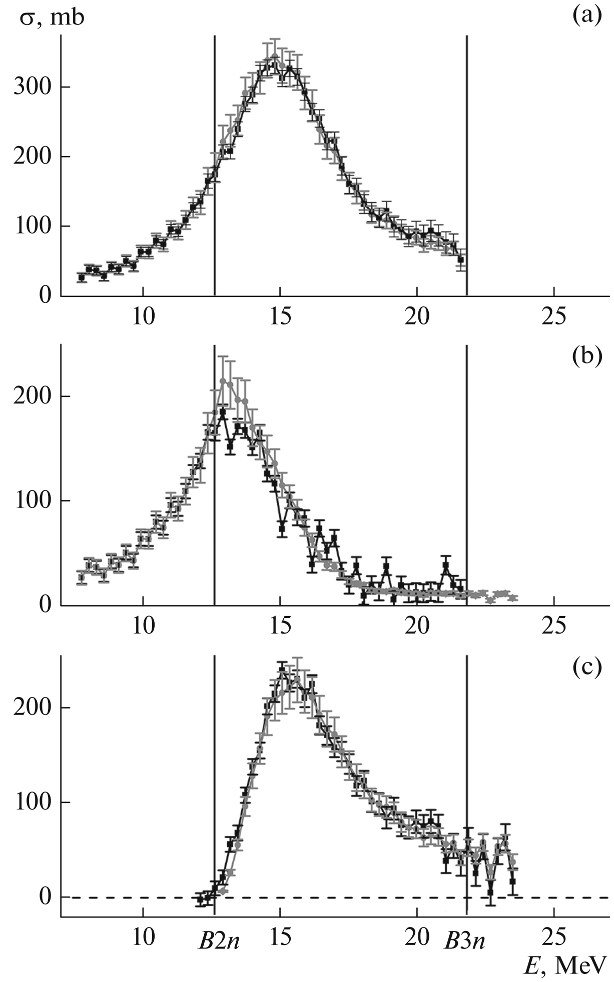


**Fig. 4.** Comparison of evaluated (circles) and experimental (squares [13]) data for the cross sections of total and partial photoneutron reactions on a $^{142}$Ce nucleus: (a) σ(γ, *xn*), (b) σ(γ, s*n*), and (c) σ(γ, 1*n*).

2*n*) by 3.0% (450.32 and 463.98 MeV mb) [13]. Such opposite directional discrepancies in reaction cross sections (γ, 1*n*) and (γ, 2*n*) convincingly show the reasons for the substantial systemic uncertainties in the results of experiment [13] (inaccurate movement of a considerable number of neutrons from channel 1*n* to channel 2*n*).

A comparison of the data shown in Figs. 1 and 3 confirms that there are substantial systematic uncertainties in the processes of neutron multiplicity sorting. The noted systematic uncertainties in the energy range of ~24–27 MeV correlate with one another: a reduction in $F_2^{\text{exp}}$ is observed, while function $F_1^{\text{exp}}$ increases. Experimental data [13] for reaction cross sections (γ, 2*n*) are unreliable because they contribute appreciably to the number of neutrons, to which multiplicity 2 is incorrectly attributed to the differences in

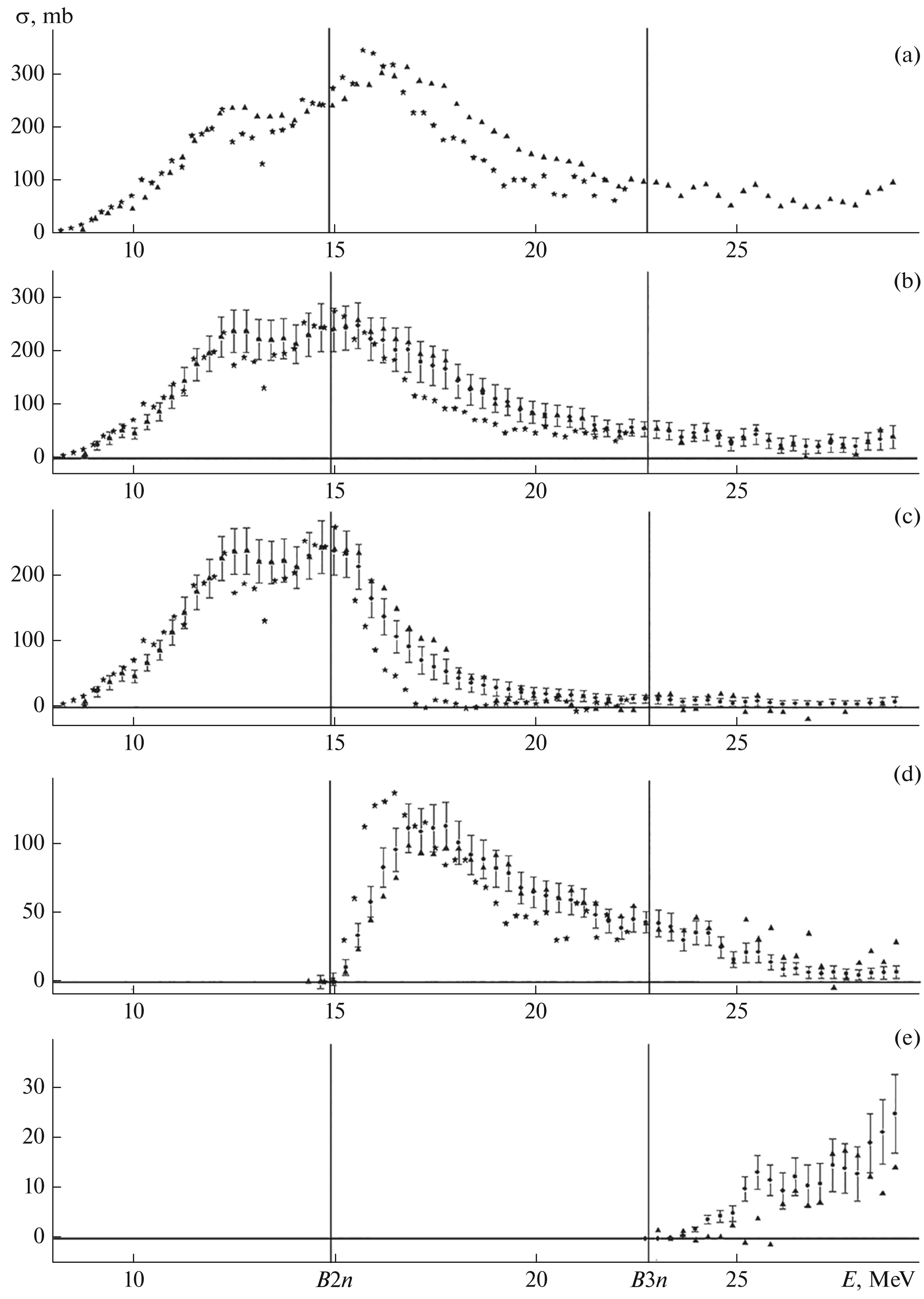


**Fig. 5.** Comparison of evaluated (circles) and experimental (triangles [14] and stars [15]) data for the cross sections of total and partial photoneutron reactions on a $^{153}$Eu nucleus: (a) σ(γ, *xn*), (b) σ(γ, s*n*), (c) σ(γ, 1*n*), (d) σ(γ, 2*n*), and (e) σ(γ, 3*n*).

the energy dependences of the $F_i^{\mathrm{exp}}$ and $F_i^{\mathrm{theor}}$ ratios for reaction cross sections (γ, 1*n*), and they are understated equally unreasonably.

### *$^{142}$Ce nucleus*

The cross sections for the partial reactions (γ, 1*n*) and (γ, 2*n*) evaluated using the experimental-theoretical method (4) with cross section $\sigma^{exp}(\gamma, xn)$ as the initial experimental data [13] are compared to the corresponding experimental data in Fig. 4. The integrated characteristics of the experimental and evaluated cross sections for all the considered partial and total reactions are given in Table 2.

The discrepancy between the experimental [13] and evaluated reaction cross sections is negligible in the energy region below the $B2n$ reaction threshold $(\gamma, 2n)$, where there is no problem of neutron multiplicity sorting: the difference between the integrated cross sections is 1.02% (406.53 and 410.70 MeV mb). The data for both reactions differ in the high-energy region, where the $(\gamma, 1n)$ and $(\gamma, 2n)$ reactions compete. Thus, $\sigma^{int\text{-}eval}(\gamma, 1n) > \sigma^{int\text{-}exp}(\gamma, 1n)$ by 3.3% (1029.30 and 995.28 MeV · mb), and $\sigma^{int\text{-}eval}(\gamma, 2n) < \sigma^{int\text{-}exp}(\gamma, 2n)$ by 2.8% (1083.79 and 1114.31 MeV mb). Such opposite directional discrepancies between the $(\gamma, 1n)$ and $(\gamma, 2n)$ reactions (as in the case of the $^{140}$Ce nucleus) convincingly illustrate the reasons for the substantial systematic uncertainties in the results of the experiment in [13] (the unreliable displacement of a considerable amount of neutrons from channel $1n$ to the channel $2n$).

Despite the irregularities in the ratios of the integrated cross sections for the $(\gamma, 1n)$ and $(\gamma, 2n)$ reactions of the $^{140,142}$Ce isotopes that were noted above and differ substantially from those for neighboring nuclei, it should be noted that such discrepancies far exceed those resulting from not satisfying the criteria of reliability. The differences between the characteristics of the cross sections for the $(\gamma, 1n)$ and $(\gamma, 2n)$ reactions for $^{140,\,142}$Ce isotopes were apparently due to the physical effects discussed in [13], and to the change in core rigidity caused by the connection between the dipole vibrations in it and surface motions.

**Table 1.** Comparison of evaluated integrated cross sections $\sigma^{int}$ (MeV mb) for the $^{140}$Ce nucleus with experimental data [13]

| | $E^{int} = B2n = 16.7$ MeV | |
|---|---|---|
| | Saclay | Evaluation |
| $(\gamma, xn)$*) | 1561.0 ± 9.9 | 1561.0 ± 9.9 |
| $(\gamma, 1n)$ | 1556.5 ± 9.7 | 1560.1 ± 35.6 |
| | $E^{int} = 26.4$ MeV | |
| | Saclay | Evaluation |
| $(\gamma, xn)$ *) | 2869.6 ± 21.9 | 2869.6 ± 21.9 |
| $(\gamma, 1n)$ | 1941.6 ± 18.5 | 1965.1 ± 37.5 |
| $(\gamma, 2n)$ | 464.0 ± 11.6 | 450.3 ± 11.8 |

* The experimental cross section in [13] was the initial one for evaluation.

**Table 2.** Comparison of evaluated integrated cross sections $\sigma^{int}$ (MeV mb) for the $^{142}$Ce nucleus and experimental data [13]

| | $E^{int} = B2n = 12.6$ MeV | |
|---|---|---|
| | Saclay | Evaluation |
| $(\gamma, xn)$ *) | 410.7 ± 8.4 | 410.7 ± 8.4 |
| $(\gamma, 1n)$ | 406.5 ± 7.7 | 410.7 ± 13.7 |
| | $E^{int} = 21.6$ MeV | |
| | Saclay | Evaluation |
| $(\gamma, xn)$ *) | 3202.1 ± 21.8 | 3197.0 ± 13.0 |
| $(\gamma, 1n)$ | 995.3 ± 14.8 | 1029.3 ± 21.1 |
| $(\gamma, 2n)$ | 1114.3 ± 16.4 | 1083.8 ± 23.0 |

* The experimental cross section [13] was the initial one for evaluation.

### *$^{153}$Eu nucleus*

The cross sections of the partial reactions $(\gamma, 1n)$ and $(\gamma, 2n)$ evaluated using the experimental-theoretical method (4) with the experimental data on cross section $\sigma^{exp}(\gamma, xn)$ as the initial data [14] are compared to the corresponding experimental data in Fig. 5. The integrated characteristics of the experimental and evaluated cross sections for all the considered partial and total reactions are given in Table 3.

Comparison of the data shown in Figs. 1 and 5 confirms that there are significant systematic uncertainties in the processes of neutron separation by multiplicity. The noted systematic uncertainties in the energy range of ~25–27 MeV correspond to definite and correlating discrepancies between the $(\gamma, 2n)$ and $(\gamma, 3n)$ reaction cross sections. Thus, in the energy region between $B3n$ and $E^{int} = 29$ MeV, $\sigma^{eval}(\gamma, 3n)$, exceeds $\sigma^{exp}(\gamma, 3n)$ by ~58% (61.0 and 38.9 MeV mb), while $\sigma^{exp}(\gamma, 2n)$ exceeds $\sigma^{eval}(\gamma, 2n)$ by ~23% (167.1 and 136.5 MeV mb). In the energy region between $B2n$ and $B3n$, $\sigma^{exp}(\gamma, 1n)$ exceeds $\sigma^{eval}(\gamma, 1n)$ by ~13% (582.0 and 517.0 MeV mb), and $\sigma^{eval}(\gamma, 2n)$ exceeds $\sigma^{exp}(\gamma, 2n)$ by ~19% (518.6 and 436.1 MeV mb).

Figure 5 shows that the cross sections for partial reactions obtained from experimental data [15] differ substabtially from both the experimental data [14] and the evaluated cross sections (in accordance with the data in Fig. 1).

As was shown in [3, 6–12, 20, 21], performed earlier for a large number of medium and heavy nuclei, an important feature of photoneutron reactions not considered in the photoneutron multiplicity sorting method [13, 14]—the complex and poorly understood connection between of the multiplicity of neutrons and their kinetic energy—is the reason for such inconsistencies. The results from detailed experimental and

**Table 3.** Comparison of integrated cross sections $\sigma^{int}$ (MeV mb) for the $^{153}$Eu nucleus and experimental data [14]

| | $E^{int} = B2n = 14.9$ MeV | | |
|---|---|---|---|
| | Saratov [15] | Livermore [14] | Evaluation |
| (γ, *xn*) | 959.0 ± 16.2 | 959.0 ± 7.5* | 959.0 ± 7.5 |
| (γ, 1*n*) | 959.1 ± 38.7 | 957.2 ± 7.4 | 954.7 ± 42.8 |
| | $E^{int} = B3n = 22.8$ MeV | | |
| (γ, *xn*) | 2345.8 ± 48.0 | 2512.0 ± 13.3* | 2512.0 ± 13.3 |
| (γ, 1*n*) | 1278.4 ± 57.6 | 1539.2 ± 14.3 | 1471.7 ± 54.5 |
| (γ, 2*n*) | 533.8 ± 48.1 | 487.6 ± 7.3 | 518.6 ± 22.6 |
| | $E^{int} = 29.0$ MeV | | |
| (γ, *xn*) | | 3025.9 ± 25.2* | 3025.9 ± 25.2 |
| (γ, 1*n*) | | 1554.1 ± 22.5 | 1529.30 ± 55.5 |
| (γ, 2*n*) | | 674.7 ± 16.2 | 655.1 ± 25.1 |
| (γ, 3*n*) | | 38.9 ± 5.3 | 61.0 ± 6.4 |

*The experimental cross section in [14] was the initial one for evaluation.

theoretical studies of the photodisintegration of the $^{181}$Ta nucleus in [17] showed that the energy spectrum of photoneutrons upon opening the GDR channels with an increasing number of outgoing neutrons changes only slightly (the main maximum slightly moves and remains in the energy range of ~0.7–1.0 MeV).

## CONCLUSIONS

The reliability of experimental data on the photodisintegration of $^{140,142}$Ce and $^{159}$Eu nuclei, which were obtained in different experiments, was investigated using objective physical reliability criteria. It was shown that the cross sections of (γ, 1*n*) and (γ, 2*n*) partial reactions, obtained in experiments [13, 14] on a beam of quasimonoenergy annihilation photons using the neutron multiplicity sorting method, do not satisfy the proposed data reliability criteria, since they contain considerable systematic uncertainties. These uncertainties are due to the proximity of the energy of neutrons from different partial reactions, which makes it difficult to determine the multiplicity of neutrons by measuring this energy. It was also found that the cross sections of reactions (γ, 1*n*) and (γ, 2*n*), obtained from experimental data on a bremsstrahlung beam [15], differ considerably from the experimental results [14] and the evaluated data.

New cross sections of partial reactions (γ, 1*n*) and (γ, 2*n*) for $^{140,142}$Ce, additionally that of (γ, 3*n*) reaction for $^{159}$Eu, as well as of total photoneutron reaction (γ, *sn*) for all three nuclei under discussion, satisfying the physical criteria of data reliability, were obtained using the experimental-theoretical method for evaluation.

It was found that the new evaluated cross sections of reactions differ considerably from the experimental data obtained using neutron multiplicity sorting method and do not satisfy the objective physical criteria of reliability. It was concluded that these discrepancies were due to the substantial systematic uncertainties of the method for determining the multiplicity of photoneutrons from their kinetic energies.

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