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Atlas of Photoneutron Cross Sections
Obtained with Monoenergetic Photons

Final Edition, 1986

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Abstract

Photoneutron cross-section and integrated cross-section data obtained with monoenergetic photons are presented in a uniform format. This compilation is current of as June 1986.

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Introduction

Over the years, a considerable body of data on photoneutron cross sections obtained with monoenergetic photons has been acquired at the Livermore, Saclay, and several other laboratories. In view of the need for a comprehensive compilation of photoneutron cross-section data, these monoenergetic-photon data are gathered together here and presented in a uniform format. This compilation updates and supersedes the earlier editions of this Atlas.¹ A more complete compilation (which includes data obtained with continuous bremsstrahlung radiation sources as well), is being assembled by the photonuclear group at the National Bureau of Standards.² A critique of monoenergetic-photon techniques and the data obtained therefrom is included in Ref. 3. The data, here made available in graphical form, also are available upon request in digital form for purposes of theoretical analysis and for those associated with applications to other scientific disciplines and technologies.

The Annihilation-Photon Technique

The experimental methods for producing beams of monoenergetic photons which have been used for photonuclear-reaction studies include the annihilation in flight of fast positrons, tagged bremsstrahlung, and nuclear γ -rays from the capture of protons or neutrons. Since most of the work surveyed here has been done with annihilation photons, a brief description of this method is given.

The annihilation-photon method for obtaining a monoenergetic photon beam was first suggested by Tzara⁴ and has been developed or studied at several laboratories since, principally at Saclay and at Livermore. The method consists of producing positrons by pair production, transporting a beam of fast positrons having the desired energy E_{e^+} to the experimental area, and allowing it to strike a thin, low-Z target, thus producing, in the forward direction, a monoenergetic beam of annihilation photons (where the photon energy $E_\gamma = E_{e^+} + 0.76$ MeV, the latter term being $3/4$ of the rest mass of the annihilating pair).

Figure A is a schematic experimental diagram illustrating the technique. Positrons are produced from the bremsstrahlung created when the intense beam of high-energy electrons from the first section of a high-current linac strikes a thick, high-Z converter. The emergent positrons are captured into the second section, with the radio frequency 180° out of phase with that normally used for electrons, and are accelerated to the desired energy. The positron beam is energy-analyzed to the desired momentum resolution with a bending magnet and slit, is transported to the experimental area, and is focused onto the thin, low-Z annihilation target. Some of the positrons annihilate in flight, producing the monoenergetic photon beam; some produce bremsstrahlung, whose effects must be subtracted out by repeating the measurement with electrons instead of positrons; and the rest are swept away from the photon beam line and into a dump hole by a magnet. The collimated photon beam passes through a transmission ion chamber beam monitor and strikes the nuclear sample under study.

This photoneutron sample is located in the center of a highly efficient 4π neutron detector, whose electronic scaling circuitry is triggered after each accelerator beam burst. The number of neutrons detected for each beam burst is recorded, and this "multiplicity-counting" system, together with a knowledge of the neutron detector efficiency, allows one to obtain the single, double, triple, etc., photoneutron cross sections simultaneously and independently. This is essential if one is to obtain directly the total photoneutron cross section, which is nearly the same as the total photoneuclear absorption cross section for medium and heavy nuclei, where proton (and other charged-particle) emission at giant-resonance energies is inhibited by the Coulomb barrier.

The ion chamber photon beam monitor is calibrated against a NaI(Tl) photon spectrometer whose response functions and absolute efficiency are measured separately. The energy resolution of the photon beam is determined primarily by the momentum spread of the positron beam, together with the dE/dx losses suffered by the positrons before annihilation, which result from the finite thickness of the annihilation target. The energy scale is set with reference to known nuclear energy levels and thresholds. Figure A also shows sample NaI photon spectra for incident positrons, incident electrons, and their difference.

Fig. A.

Schematic diagram of an annihilation-photon-induced photoneutron experiment (see text). The diagram is considerably simplified and is not to scale; shielding walls have been omitted for clarity. Inset: NaI spectra of positron- and electron-induced photon beams and their difference. The (poor) resolution is that of the NaI spectrometer.

Data

The data are presented graphically, generally in order of increasing mass number. Figure 8 (p. 27), in the form of a chart of the stable (or long-lived) nuclei, constitutes an index of the isotopes studied to date with monoenergetic photons. When two or more laboratories have measured the same nucleus, the data are presented in chronological order. The top data plot for each nucleus is the photoneutron yield cross section $\sigma[(\gamma,n) + (\gamma,pn) + 2(\gamma,2n) + 2(\gamma,p2n) + 3(\gamma,3n) + \dots]$; below it are the total photoneutron cross section $\sigma[(\gamma,n) + (\gamma,pn) + (\gamma,2n) + (\gamma,p2n) + (\gamma,3n) + \dots]$, the single photoneutron cross section $\sigma[(\gamma,n) + (\gamma,pn)]$, the double photoneutron cross section $\sigma[(\gamma,2n) + (\gamma,p2n)]$, and the triple photoneutron cross section $\sigma(\gamma,3n)$. [Sometimes another cross section is substituted for $\sigma(\gamma,3n)$ -- see Explanation of the Graphs.] Most of the total photoneutron data plots for medium and heavy nuclei have Lorentz-curve fits superposed.

A table of properties of the giant dipole resonance derived from measurements made with monoenergetic photon beams also is included. Integrated cross sections and their moments, derived directly from the data, constitute about half the table, and the parameters of Lorentz curves fitted to the giant-resonance data the other half. Numerous quantities of physical interest can be derived from these integrated cross sections and Lorentz parameters; a detailed exposition of these is given in Ref. 3. The "Reference" and "Laboratory" columns constitute an index to the monoenergetic-photon-data references. The references to the tables (through 1982) follow the notation of Ref. 2.

In the semiclassical theory of the interaction of photons with nuclei, the shape of a fundamental resonance in the absorption cross section is that of the Lorentz curve:^{5,6}

$$\sigma(E) = \frac{\sigma_m}{1 + [(E - E_m)^2 / E^2 T^2]} \quad (1)$$

where the Lorentz parameters E_m , σ_m , and Γ are the resonance energy, peak cross section, and full width at half-maximum, respectively. In the hydrodynamic theory of photonuclear reactions, the giant dipole resonance consists of one such Lorentz line for spherical nuclei,^{5,7} corresponding to the absorption of photons which induce oscillations of the neutron and proton fluids in the nucleus against each other, and the superposition of two such lines for statically deformed spheroidal nuclei,^{6,8} corresponding to oscillations along each of the nondegenerate axes of the spheroid. (The lower-energy line corresponds to oscillations along the longer axis and the higher-energy line along the shorter, since the absorption frequency decreases with increasing nuclear dimensions.)

$$\sigma(E) = \sum_{i=1}^2 \frac{\sigma_{mi}}{1 + [(E^2 - E_{mi}^2)^2 / E_i^2 \Gamma_i^2]} \quad (2)$$

where $i=1, 2$ corresponds to the lower- and higher-energy lines. Note that the two Lorentz lines are noninterfering and that the damping parameters Γ_i are not energy-dependent.

The Thomas-Reiche-Kuhn (TRK) sum rule⁹ is an expression giving the total integrated cross section for electric-dipole photon absorption, in the absence of exchange forces, and is given by:

$$\int_0^\infty \sigma(E) dE = \frac{2\pi^2 e^2 \hbar}{Mc} \frac{NZ}{A} = 60 \left(\frac{NZ}{A} \right) \text{ MeV-mb} \quad (3)$$

where M is the nucleon mass and the integration is over all energies for which dipole absorption can occur. It should be noted that the area under the Lorentz curve (from Eq. 1 or 2) is given by:

$$\int_0^\infty \sigma(E) dE = \frac{\pi}{2} \sigma_m \Gamma \quad (\text{or } \frac{\pi}{2} \sum_{i=1}^2 \sigma_{mi} \Gamma_i). \quad (4)$$

The first moment of the integrated cross section, also known as the "bremsstrahlung-weighted" cross section (since the energy dependence of the bremsstrahlung spectrum often is approximated by $1/E$), is given by:

$$\sigma_{-1} = \int_0^{\infty} [\sigma(E)/E] dE = \frac{4\pi^2}{3} \frac{e^2}{hc} \frac{NZ}{A-1} \langle r^2 \rangle \quad (5)$$

for light nuclei,⁹ where $\langle r^2 \rangle$ is the mean-square radius of the nuclear charge distribution.

The second moment of the integrated cross section σ_{-2} is proportional to the nuclear polarizability $p = (e^2 R^2 A / 40K)$ and hence increases with the diffuseness of the nucleus. Here R is the radius of the equivalent spherical nucleus and K is the nuclear symmetry energy. Then the Migdal sum rule^{9,10} states that:

$$\sigma_{-2} = \int_0^{\infty} [\sigma(E)/E^2] dE = \frac{2\pi^2}{hc} p = \frac{\pi^2}{20} \frac{e^2}{hc} \frac{R^2 A}{K} \quad (6)$$

Higher-Energy Data

A few photoneutron cross-section measurements with monoenergetic photons have been performed at energies substantially above the giant dipole resonance, notably at Saclay. These are not presented here; one should refer to the original data references.¹¹⁻¹³ Some additional implications of these higher-energy data are discussed in Refs. 14 and 15 as well.

Policy

No attempt is made here to evaluate the data; that is, to choose between two sets of data for the same nucleus measured at different laboratories or to compromise between them by presenting a set of recommended intermediate values. It should be noted, however, that the overall agreement and consistency between measurements made with monoenergetic photons are very good indeed; when they are not, one usually (but not always) is best advised to weigh more recent data more heavily than earlier data.

Notes on References

When data from this Atlas are cited, reference should be made to the original publication as well.

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Explanation of the Table

$E_{\gamma\max}$ The upper-energy limit of the data

$\sigma_{\text{int}}(\gamma, Sn)$ The integrated photoneutron yield cross section:

$$\sigma_{\text{int}}(\gamma, Sn) = \int_{E_{\text{thr}}(\gamma, n)}^{E_{\gamma\max}} \sigma(\gamma, Sn) dE_{\gamma}$$

where $E_{\text{thr}}(\gamma, n)$ is the photoneutron threshold energy,

$$\sigma(\gamma, Sn) = \nu(\gamma, \text{tot}) + \sigma(\gamma, 2n) + 2\sigma(\gamma, 3n) + (\nu-1)\sigma(\gamma, f),$$

$$\sigma(\gamma, \text{tot}) = \sigma(\gamma, 1n) + \sigma(\gamma, 2n) + \sigma(\gamma, 3n) + \sigma(\gamma, f),$$

$$\sigma(\gamma, 1n) = \sigma(\gamma, n) + \sigma(\gamma, pn),$$

$$\sigma(\gamma, 2n) = \sigma(\gamma, 2n) + \sigma(\gamma, p2n),$$

$$\sigma(\gamma, f) = \sigma(\gamma, F) + \sigma(\gamma, nF), \text{ and}$$

ν is the average prompt photofission neutron multiplicity.

$\sigma_{\text{int}}(\gamma, \text{tot})$ The integrated total photoneutron cross section:

$$\sigma_{\text{int}}(\gamma, \text{tot}) = \int_{E_{\text{thr}}(\gamma, n)}^{E_{\gamma\max}} \sigma(\gamma, \text{tot}) dE_{\gamma}$$

$\sigma_{\text{int}}(\gamma, 1n)$ The integrated single photoneutron cross section:

$$\sigma_{\text{int}}(\gamma, 1n) = \int_{E_{\text{thr}}(\gamma, n)}^{E_{\gamma\max}} \sigma(\gamma, 1n) dE_{\gamma}$$

$\sigma_{int}(\gamma, 2n)$ The integrated double photoneutron cross section:

$$\sigma_{int}(\gamma, 2n) = \int_{E_{thr}(\gamma, 2n)}^{E_{\gamma max}} \sigma(\gamma, 2n) dE_{\gamma}$$

where $E_{thr}(\gamma, 2n)$ is the threshold energy for the photoejection of two neutrons

$\sigma_{int}(\gamma, 3n)$ The integrated triple photoneutron cross section:

$$\sigma_{int}(\gamma, 3n) = \int_{E_{thr}(\gamma, 3n)}^{E_{\gamma max}} \sigma(\gamma, 3n) dE_{\gamma}$$

where $E_{thr}(\gamma, 3n)$ is the threshold energy for the photoejection of three neutrons. For ^{16}O , ^{31}P , ^{32}S , and ^{39}K , $\sigma_{int}(\gamma, pn)$ appears in this column; for ^{18}O , $c_{int}(\gamma, p)$ appears here; and for the actinide nuclei:

$$\sigma_{int}(\gamma, f) = \int_{B_F}^{E_{\gamma max}} \sigma(\gamma, f) dE_{\gamma}$$

where $\sigma(\gamma, f)$ is the sum of the first- and second-chance photofission cross sections $\sigma(\gamma, F)$ and $c(\gamma, nF)$, respectively, and B_F is the energy of the photofission barrier

σ_{-1} The first moment of the integrated total photoneutron cross section:

$$\sigma_{-1} = \int_{E_{thr}(\gamma, n)}^{E_{\gamma max}} [\sigma(\gamma, tot)/E_{\gamma}] dE_{\gamma}$$

σ_{-2}

The second moment of the integrated total photoneutron cross section:

$$\sigma_{-2} = \int_{E_{thr}(\gamma,n)}^{E_{\gamma max}} [\sigma(\gamma, tot)/E_{\gamma}^2] dE_{\gamma}$$

Fitting
Interval

The photon energy interval over which the Lorentz-curve fits to the data were made

$E_{mi}, \sigma_{mi}, \Gamma_i$

The parameters of the Lorentz curves fitted to the data within the fitting interval given in the preceding column. The Lorentz curves are of the form:

$$\sigma(E_{\gamma}) = \sum_i \sigma_{mi} / \left\{ 1 + [(E_{\gamma}^2 - E_{mi}^2)^2 / E_{\gamma}^2 \Gamma_i^2] \right\} \quad ;$$

for spherical nuclei, $i=1$; for deformed nuclei, $i=1,2$. Here "spherical" merely indicates that a one-component Lorentz curve gives a better fit to the data than a two-component one, and "deformed" indicates the opposite. The fitting procedure used is the standard best-least-squares method, wherein the squares of the residuals are weighted with the inverse squares of the statistical uncertainties.

Reference

The data references follow the table.

Laboratory

The laboratory at which the data were obtained:

L - Livermore

S - Saclay

G - Giessen

GA - General Atomic

I - Illinois

P - Pennsylvania

Nucleus	$E_{\gamma \max}$ (MeV)	$\sigma_{int}(\gamma, Sn)$ (MeV-mb)	$\sigma_{int}(\gamma, tot)$ (MeV-mb)	$\sigma_{int}(\gamma, 1n)$ (MeV-mb)	$\sigma_{int}(\gamma, 2n)$ (MeV-mb)	$\sigma_{int}(\gamma, 3n)$ (MeV-mb)	$\sigma_1(\gamma, tot)$ (mb)	$\sigma_2(\gamma, tot)$ (mb-MeV ⁻¹)	Fitting Interval (MeV)	Lorentz Parameters						Reference	Laboratory	Figure Number
										E_{m1} (MeV)	σ_{m1} (mb)	Γ_1 (MeV)	E_{m2} (MeV)	σ_{m2} (mb)	Γ_2 (MeV)			
³ H	23.4	32.3	22.0	11.7	10.2 ^h		1.48	0.11								81Fa1	L	1
³ He	30.2	13.0	13.0	13.0			0.77	0.05								74Be8	L	2
³ He	25.8	14.1	14.1	14.1			0.83	0.05								81Fa1	L	3
⁴ He	31.4	7.9	7.9	7.9	0		0.30	0.01								71Be3	L	4
⁴ He	47.3	23.5	23.5	23.5			0.73	0.02								80Be1	L	5
⁶ Li	32.0	28.2	27.8	27.4	0.4		1.91	0.16								65Be1	L	6
⁷ Li	30.5	30.2	20.1	10.0	10.1		1.15	0.07								73Br11	L	7
⁹ Be	37.0	83.7	58.1	32.5	25.6		2.52	0.13								75Kn5	G	8
¹⁰ B	35.1	84.3	82.3	80.4	1.9		3.69	0.18								76Kn3	G	9
¹¹ B	35.1	84.1	69.2	54.3	14.9		2.93	0.13								76Kn3	G	10
¹² C	26.7	34.5	34.5	34.5			1.47	0.063								62De1 66Lo1	P	11
¹² C	25.5	29.4	29.4	29.4												66Ni2	S	
¹² C	37.4	46.8	46.8	46.8	0		1.83	0.073								66Fu1	L	12
¹² C	32.1	51.6	51.6 ^a				2.08 ^a	0.085 ^a								75Kn8	G	13
¹² C	41.8	131	126	121	4.7		5.72	0.306								79Ju3	L	14
¹² C	36.2	163	126	89.7	36.6		6.09	0.322								85Py1	L	15
¹⁴ N	29.5	98	98	98			4.36	0.20								70Be8	L	16
¹⁵ N	38.0	114	106	98.8	7.6		4.65	0.218								82Ju2	L	17
¹⁶ O	26.5	41.5	41.5	41.5												66Ni2	S	
¹⁶ O	28.0	41.5	41.5	41.5			1.76	0.075								64Br1 65Ca1	L	18
¹⁶ O	37.1	80.1	79.6	78.9	0.6	11 ^p	3.04	0.119								74Ve1	S	19
¹⁶ O	37.0	62.9	62.9	62.9	0		2.40	0.094								75Kn8	G	20
¹⁶ O	33.1	61.5	61.5	61.5			2.51	0.105								83Be1	L	21
¹⁷ O	39.7	128	118	109	9.3		5.22	0.266								80Ju4	L	22
¹⁸ O	41.8	275	198	121	77	44 ^q	9.08	0.483								79Mo1	L	23
¹⁸ O	33.0	191	142	93	49		6.90	0.38								76Kn4	G	24
¹⁹ F	27.8	109	104	99	5.2		4.95	0.25								74Ve1	S	25

Nucleus	$E_{\gamma \text{ max}}$ (MeV)	$\sigma_{\text{int}}(\gamma, \text{Sn})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{tot})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, n)$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, 2n)$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, 3n)$ (MeV-mb)	$\sigma_{-1}(\gamma, \text{tot})$ (mb)	$\sigma_{-2}(\gamma, \text{tot})$ (mb-MeV ⁻¹)	Fitting Interval (MeV)	Lorentz Parameters						Reference	Laboratory	Figure Number
										E_{m1} (MeV)	σ_{m1} (mb)	Γ_1 (MeV)	E_{m2} (MeV)	σ_{m2} (mb)	Γ_2 (MeV)			
NatNe	25.9	46	43	40	3.1		1.98	0.09								74Ve1	S	26
²³ Ne	27.1	120	119	118	0.6		5.74	0.29								71Al1	L	27
²³ Ne	30.1	139	136	133	2.7		6.18	0.29								74Ve1	S	28
NatMg	26.0	58	58 ^a													66Mi2	S	
NatMg	28.0	75.6	75.6	75.6												71Fu2	L	
²⁶ Mg	28.3	51.9	51.9	51.9			2.37	0.11								71Fu2	L	29
²⁷ Mg	28.9	248	247	245	1.5		11.5	0.56								71Al1	L	30
²⁸ Mg	28.6	308	236	164	72		11.5	0.59								71Fu2	L	31
²⁷ Al	36.7	175	167	159	7.6		7.17	0.32								66Fu1	L	32
²⁷ Al	30.3	152	151	150	0.6		6.77	0.31								74Ve1	S	33
NatSi	30.0	95	95	95			4.25	0.19								74Ve1	S	34
²⁸ Si	32.1	105	105	105	0		4.46	0.20								83Py1	L	35
²⁹ Si	33.1	199	199	199	0		9.66	0.51								83Py1	L	36
³⁰ Si	33.1	316	249	181	67		12.1	0.64								83Py1	L	37
³¹ P	26.6	180	179	178	1.1	44 ^D	8.34	0.40								74Ve1	S	38
³² S	32.2	98	98	98	0.1	14 ^F	4.24	0.19								74Ve1	S	39
NatCl	27.6	292	273	254	19		13.3	0.67								74Ve1	S	40
NatK	31.6	218	217	216	1.1	39 ^S	9.7	0.45								74Ve1	S	41
³⁶ Ar	26.8	538	390	242	148		21.0	1.18								74Ve1	S	42
⁴⁰ Ca	26.0	73	73	73												66Mi2	S	
⁴⁰ Ca	29.5	100	100	100			4.55	0.21								74Ve1	S	43
⁴⁵ Sc	28.1	399	382	365	17		19.6	1.05								74Ve1	S	44
⁵¹ V	27.8	654	552	450	102		28.9	1.56	14-23	17.86	58.8	4.42	21.22	28.8	5.10	62Fu1	L	45
⁵¹ V	27.8	689	610	531	79		31.2	1.65	14-23	17.93	53.3	3.62	20.95	40.7	7.15	74Ve1	S	46
⁵⁵ Mn	36.5	902	733	567	163	3	36.4	1.93	14-21	16.82	51.4	4.33	20.09	45.2	4.09	79At2	L	47
⁵⁹ Ni	33.5	214	286	278	7.7		13.8	0.70								74Fu3	L	48

Nucleus	$E_{\gamma\max}$ (MeV)	$\sigma_{int}(\gamma,Sn)$ (MeV-mb)	$\sigma_{int}(\gamma,tot)$ (MeV-mb)	$\sigma_{int}(\gamma,1n)$ (MeV-mb)	$\sigma_{int}(\gamma,2n)$ (MeV-mb)	$\sigma_{int}(\gamma,3n)$ (MeV-mb)	$\sigma_1(\gamma,tot)$ (mb)	$\sigma_2(\gamma,tot)$ (mb-MeV ⁻¹)	Fitting Interval (MeV)	Lorentz Parameters						Reference	Laboratory	Figure Number
										E_{m1} (MeV)	σ_{m1} (mb)	Γ_1 (MeV)	E_{m2} (MeV)	σ_{m2} (mb)	Γ_2 (MeV)			
⁵⁹ Co	36.5	965	807	653	150	4	40.1	2.14	14-21	16.43	28.3	2.73	18.66	58.4	7.38	79A12	L	49
⁶⁰ Ni	33.2	772	700	628	72	0	35.4	1.89	14-21	16.30	34.1	2.44	18.51	55.2	6.37	74Fu3	L	50
NatCu	19.6	450	450 ^a													62M13	S	
NatCu	27.8	710	604	498	106		33.8	1.97								64Fu1	L	51
⁶³ Cu	27.8	680	604	528	76		33.4	1.92	14-21	16.24	60.8	4.65	19.65	26.8	4.59	64Fu1	L	52
⁶³ Cu	25.1			498 ^b	43				14-21	16.72	66.1	4.19	19.10	30.1	3.56	68Su1	GA	53
⁶⁴ Zn	29.5	791	747	703	44		38.1	2.03	14-21	16.23	41.4	3.27	19.19	56.1	5.98	76Ca1	S	54
⁶⁵ Cu	27.8	817	619	421	198		36.0	2.18	14-20	16.70	75.2	6.89				64Fu1	L	55
NatGa	26.5	1108	912	716	136		52.0	3.09	13-21	16.69	107	6.91				76Ca1	S	56
⁷⁰ Ge	26.5	855	771	687	84		43.2	2.51	13-21	16.79	89.4	7.66				76Ca1	S	57
⁷² Ge	26.5	1133	935	737	198		53.5	3.19	13-21	16.67	107	7.68				76Ca1	S	58
⁷⁴ Ge	26.5	1322	1013	704	309		58.8	3.56	13-21	14.52	23.9	1.92	17.02	102.3	8.18	76Ca1	S	59
⁷⁵ As	29.5	1130	909	688	221	0	51.4	3.05	13-21	14.98	41.1	3.64	17.61	76.9	7.26	69Be1	L	60
⁷⁵ As	26.2	1306	1089	872	217		62.7	3.76	13-21	15.23	69.2	4.52	18.24	74.6	7.75	76Ca1	S	61
⁷⁶ Ge	26.5	1487	1110	733	377	0	63.8	3.86	13-21	15.51	59.4	4.36	18.83	73.0	11.44	76Ca1	S	62
⁷⁶ Se	26.5	1177	996	815	181		57.0	3.39	13-21	14.95	68.2	3.84	18.40	81.8	6.47	76La1	S	63
⁷⁸ Se	26.5	1322	1050	778	272		61.4	3.74	13-21	15.23	35.8	2.58	17.18	101.8	8.55	76Ca1	S	64
⁸⁰ Se	28.1	1527	1138	749	389	0	65.9	3.99	13-21	16.53	136	6.90				76Ca1	S	65
⁸² Se	26.5	1521	1124	727	397	0	66.4	4.11	13-21	16.65	148	5.91				76Ca1	S	66
NatRb	24.3	1242	1147	1052	95		67.1	4.04	14-19	16.80	190	4.47				71Le1	S	67
NatSr	27.0	1553	1432	1311	121		80.3	4.68	14-19	16.84	206	4.50				71Le1	S	68
⁸⁹ Y	28.0	1158	1059	960	99		59.8	3.48	14-19	16.79	185	3.95				67Be2	L	69
⁸⁹ Y	27.0	1427	1353	1279	74		76.5	4.46	14-19	16.74	226	4.25				71Le1	S	70
⁸⁹ Y	18.1	641	641				40.0	2.52	14-19 ^{jj}	16.83	205	3.69				72Ye	I	71
NatZr	19.7	1079	991	903	88		68	4.9	14-19	16.52	174	4.41				80Be1	L	
⁹⁰ Zr	27.6	1158	1060	962	98		59.1	3.38	14-19	16.85	185	4.02				67Be2	L	72

Nucleus	$E_{\gamma\max}$ (MeV)	$\sigma_{int}(\gamma, in)$ (MeV-mb)	$\sigma_{int}(\gamma, tot)$ (MeV-mb)	$\sigma_{int}(\gamma, in)$ (MeV-mb)	$\sigma_{int}(\gamma, in)$ (MeV-mb)	$\sigma_{int}(\gamma, tot)$ (MeV-mb)	$\sigma_{-1}(\gamma, tot)$ (mb)	$\sigma_{-2}(\gamma, tot)$ (mb-MeV ⁻¹)	Fitting Interval (MeV)	Lorentz Parameters						Reference	Laboratory	Figure Number
										E_{m1} (MeV)	σ_{m1} (mb)	Γ_1 (MeV)	E_{m2} (MeV)	σ_{m2} (mb)	Γ_2 (MeV)			
⁹⁰ Zr	25.9	1309	1260	1211	49		70.8	4.08	14-19	16.74	211	4.16				71Le1	S	73
⁹¹ Zr	30.0	1303	1103	903	200	0	65.4	4.07	14-19	16.58	184	4.20				67Be2	L	74
⁹² Zr	27.8	1543	1091	639	452	0	64.2	3.92	14-19	16.26	166	4.68				67Be2	L	75
⁹² Mo	29.5	1109	1079	1049	30		57.4	3.16	14-19	16.82	162	4.14				74Be3	S	76
⁹³ Nb	24.3	1610	1331	1052	279		76.5	4.80	14-19	16.59	200	5.05				71Le1	S	77
⁹⁴ Zr	31.1	1767	1121	508	580	33	68.5	4.40	14-19	16.22	161	5.29				67Be2	L	78
⁹⁴ Mo	28.4	1665	1352	1039	313		72.3	4.73	14-19	16.36	185	5.50				74Be3	S	79
⁹⁶ Mo	27.8	1921	1483	1045	438	t	87.6	5.44	13-19	16.20	185	6.01				74Be3	S	80
⁹⁸ Mo	26.8	2100	1518	940	574	4 ^u	92.1	5.89	13-19	15.80	189	5.94				74Be3	S	81
¹⁰⁰ Mo	27.0	2270	1528	811	692	25 ^v	93.6	6.06	12-20	15.74	171	7.81				74Be3	S	82
¹⁰³ Rh	25.8	1948	1568 ^b	1188	380		94.7	5.97	13-19	16.16	191	7.26				74Le1	S	83
¹⁰⁴ Pd	21.3	1651	1381	1111	270		88.5	5.88	13-19	15.92	199	7.18				74Le1	S	84
¹⁰⁷ Ag	29.5	1619	1356	1093	263	0	78.7	4.82	13-19	15.90	150	6.71				69Be1	L	85
¹⁰⁷ Ag	24.9	1922	1643 ^c	1364	279		98.9	6.20	13-19	16.07	199	7.38				74Le1	S	86
¹⁰⁸ Cd	24.6	2016	1685 ^d	1324	361	0	106	6.96	13-19	15.81	227	6.22				74Le1	S	87
¹¹³ In	31.1	2409	1875	1354	508	13	113	7.13	13-18	15.63	266	5.24				69Fu1	L	88
¹¹³ In	24.1	2026	1748 ^c	1470	272		108	5.91	13-18	15.72	247	5.60				74Le1	S	89
¹¹⁶ Sn	29.6	2083	1669	1255	414	0	99	6.13	13-18	15.68	266	4.19				69Fu1	L	90
¹¹⁶ Sn	22.1	1823	1630 ^c	1437	193		104	6.78	13-18	15.56	271	5.08				74Le1	S	91
¹¹⁷ Sn	31.1	2446	1894	1380	476	38	114	7.30	13-18	15.66	254	5.02				69Fu1	L	92
¹¹⁷ Sn	21.1	1774	1554	1334	220		102	7.05	13-18	15.64	259	5.04				74Le1	S	93
¹¹⁸ Sn	30.8	2424	1853	1302	531	20	110	6.83	13-18	15.59	256	4.77				69Fu1	L	94
¹¹⁸ Sn	21.6	1893	1635	1377	258		106	7.07	13-18	15.44	276	4.86				74Le1	S	95
¹¹⁹ Sn	31.1	2728	1993	1326	597	69	118	7.55	13-18	15.53	253	4.81				69Fu1	L	96
¹²⁰ Sn	29.9	2771	2074	1389	673	12	124	7.79	13-18	15.40	280	4.89				69Fu1	L	97
¹²⁰ Sn	22.4	2169	1770 ^c	1371	399		113	7.49	13-18	15.37	285	5.10				74Le1	S	98

Nucleus	$E_{\gamma \text{ max}}$ (MeV)	$\sigma_{\text{int}}(\gamma, \text{Sn})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{Zr})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{In})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{Sn})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{Zn})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{Sn})$ (MeV-mb)	$\sigma_{-1}(\gamma, \text{tot})$ (mb)	$\sigma_{-2}(\gamma, \text{tot})$ (mb-MeV ⁻¹)	Fitting Interval (MeV)	Lorentz Parameters						Reference	Laboratory	Figure Number
											E_{m1} (MeV)	σ_{m1} (mb)	Γ_1 (MeV)	E_{m2} (MeV)	σ_{m2} (mb)	Γ_2 (MeV)			
¹²⁴ Sn	31.1	2790	2010	1285	670		55	123	8.02	13-18	15.19	283	4.81				69Fu1	L	94
¹²⁴ Sn	21.6	2060	1556 ^B	1056	502			101	6.74	13-18	15.28	276	4.80				74Le1	S	100
^{nat} Sb	25.7	2315	1927 ^C	1539	308		0	119	7.69	13-18	15.48	277	5.05				74Le1	S	101
¹²⁴ Te	26.5	2498	2022	1546	476		0	127	8.29	12-19	15.24	281	5.56				76Le2	S	102
¹²⁴ Te	24.8	2533	2023	1513	510			129	8.56	12-19	15.17	296	5.44				76Le2	S	103
¹²⁷ I	29.5	2171	1728	1285	443		<20	105	6.70	12-20	14.24	118	3.24	16.27	149	5.27	66Br1	L	104
¹²⁷ I	24.9	2380	1989	1601	390 ^I		w	128	8.53	12-20	14.57	239	4.08	16.69	118	4.92	69Be6	S	105
¹²⁷ I	16.9	1043	1036	1030	6			74	5.4	12-20 ^{JJ}	14.74	111	3.34	15.88	156	6.44	86Be1	L	
¹²⁸ Te	26.2	2732	2093	1454	639		0	134	8.92	12-19	15.13	305	5.36				76Le2	S	106
¹³⁰ Te	25.9	2893	2180	1467	713		0	139	9.27	12-19	15.12	320	5.03				76Le2	S	107
^{nat} Te	25.7	2636	2112	1588	524		0	134	9.05	12-19	15.46	297	5.32				74Le1	S	108
¹³³ Cs	29.5	2505	1986	1475	503		8	124	8.09	12-19	15.25	287	5.01				69Be1	L	109
¹³³ Cs	24.2	2484	2156	1828	328			137	9.09	12-19	15.34	317	5.31				74Le1	S	110
^{nat} Ba	24.3	2619	2248	1877	371		0	146	9.94	12-19	15.29	356	4.89				71Be4	S	111
¹³⁸ Ba	27.1	2536	2040	1547	490		3 ^X	130	8.71	12-19	15.26	327	4.61				70Be8	L	112
¹³⁹ La	21.2	1910	1910 ^B														62M13 68Be5 71Be4	S	
¹³⁹ La	24.3	2269	1978	1687	291 ^J		y	128	8.54	12-19	15.24	336	4.47					S	113
^{nat} Ce	21.2	1880	1880 ^B														62M13	S	
¹⁴⁰ Ce	26.5	2855	2398	1941	457		0	153	10.3	12-19	15.04	383	4.41				76Le2	S	114
¹⁴¹ Pr	29.8	2412	2062	1717	340		5 ^Z	128	8.37	12-19	15.15	324	4.42				66Br1	L	115
¹⁴¹ Pr	23.7			1713 ⁹						12-19	15.23	341	4.00				70Su1	GA	116
¹⁴¹ Pr	16.9	1422	1422	1422				101	7.31	12-19 ^{JJ}	15.04	347	4.49				71Be4	S	117
¹⁴¹ Pr	18.1	1395	1395 ^B					94 ^A	6.41 ^A	12-19 ^{JJ}	15.36	332	4.07				72Vo 80Ca1	I	118
¹⁴¹ Pr	16.2	1252	1252	1252				93	7.0	12-19 ^{JJ}	15.19	344	4.24				86Be2	L	
¹⁴¹ Pr	16.9	1264	1264	1264				89	6.4	12-19 ^{JJ}	15.19	340	4.15				86Be1	L	

Nucleus	$E_{\gamma \max}$ (MeV)	$\sigma_{int}(\gamma, Sn)$ (MeV-mb)	$\sigma_{int}(\gamma, tot)$ (MeV-mb)	$\sigma_{int}(\gamma, in)$ (MeV-mb)	$\sigma_{int}(\gamma, 2n)$ (MeV-mb)	$\sigma_{int}(\gamma, 3n^1)$ (MeV-mb)	$\sigma_{-1}(\gamma, tot)$ (mb)	$\sigma_{-2}(\gamma, tot)$ (mb-MeV ⁻¹)	Fitting Interval (MeV)	Lorentz Parameters						Reference	Laboratory	Figure Number
										E_{m1} (MeV)	σ_{m1} (mb)	Γ_1 (MeV)	E_{m2} (MeV)	σ_{m2} (mb)	Γ_2 (MeV)			
¹⁴² Ce	23.5	3394	2206	1022	1186	0	150	10.7	12-19	14.86	332	5.10				76Le2	S	119
¹⁴² Nd	18.0	1882	1559	1236	323		112	8.46	12-19 ³³	14.92	315	4.70				71Be4	S	120
¹⁴² Nd	20.2	1918	1873	1828	45		126	8.66	12-19	14.94	359	4.44				71Ca1	S	121
¹⁴² Nd	19.8	2054	1875	1696	179		130	9.39	12-19	15.01	349	4.75				71Ca1	S	122
¹⁴² Nd	20.2	2445	1882	1319	563		128	9.01	12-19	15.05	317	5.28				71Ca1	S	123
¹⁴⁴ Sm	20.8	1970	1935	1900	35		126	8.41	12-19	15.32	383	4.45				74Ca5	S	124
¹⁴⁴ Nd	20.2	2694	2037	1380	657	0	147	11.3	12-19	14.95	296	6.31				71Ca1	S	125
¹⁴⁶ Nd	20.2	2587	1920	1253	667		133	9.60	12-19	14.74	310	5.78				71Ca1	S	126
¹⁴⁶ Nd	18.8	2537	1702	867	835		122	9.02	10.8-18.8	12.76	107	3.97	15.48	220	5.30	71Ca1	S	127
¹⁴⁸ Sm	20.0	2498	1942	1386	556		134	9.51	12-19	14.82	339	5.09				74Ca5	S	128
¹⁴⁸ Nd	20.2	3185	2011	1174	837	0	142	10.4	10.8-18.8	12.30	175	3.38	16.04	223	5.17	71Ca1	S	129
¹⁵⁰ Sm	19.8	2687	1991	1295	696		141	10.3	12-19	14.61	312	5.97				74Ca5	S	130
¹⁵² Sm	20.0	2707	2026	1345	681		143	10.5	10.8-18.8	12.38	176	2.97	15.74	234	5.22	74La5	S	131
¹⁵² Eu	28.9	3017	2273	1566	670	37	148	10.2	10.8-18.8	12.33	185	2.75	15.79	222	5.83	69Be8	L	132
¹⁵² Sm	21.1	2871	2059	1277	782		144	10.6	10.8-18.8	12.27	181	2.95	15.94	215	5.70	74Ca5	S	133
¹⁵² Sm	25.2	3247	2425	1628	772	25 ^{BB}	164	11.7								69Be6	S	134
¹⁵³ Tb	28.0	3187	2300	1413	887 ^k		151	10.5	10.8-18.8	12.22	181	2.64	15.67	220	4.97	64Br1	L	135
¹⁵³ Tb	27.4	3194	2557	1936	605	16 ^{bb}	170	12.0	10.8-18.8	12.07	196	2.98	15.88	248	5.10	68Be5	S	136
¹⁶⁰ Gd	29.5	3748	2533	1398	1055	80	169	12.1	10.8-18.8	12.23	215	2.77	15.96	233	5.28	69Be8	L	137
¹⁶⁰ Ho	19.6	2540	2540 ^f							12.02	238	2.35	15.59	308	4.85	66Ax1	S	
¹⁶² Ho	28.9	3355	2523	1736	744	44	166	11.6	10.3-18.8	12.28	214	2.57	15.78	246	5.00	69Be8	L	136
¹⁶² Ho	26.8	3667	2871	2090	766	15 ^{CC}	194	13.9	10.8-18.8	12.01	239	2.52	15.59	291	5.12	68Be5	S	139
¹⁶² Er	21.1	2973	2387	1801	586 ¹	dd	172	12.9	10.8-18.8	12.12	242	2.76	15.58	259	4.74	69Be6	S	140
¹⁷³ Lu	23.0	3142	2507	1872	635 ^m	ee	173	12.5	10.8-18.8	12.32	217	2.57	15.47	287	4.70	69Be6	S	141
¹⁸¹ Ta	22.0	2970	2970 ^a													62H13	S	
¹⁸¹ Ta	24.6	3062	2181	1300	881 ^k		149	10.7	10.8-18.8	12.54	154	1.67	14.95	273	5.23	63Br1	L	142

Nucleus	$E_{\gamma \text{ max}}$ (MeV)	$\sigma_{\text{int}}(\gamma, \text{Sn})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{tot})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{In})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{2n})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{3n})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{tot})$ (mb)	$\sigma_{\text{2}}(\gamma, \text{tot})$ (mb-MeV ⁻¹)	Fitting Interval (MeV)	Lorentz Parameters						Reference	Laboratory	Figure Number
										E_{m1} (MeV)	σ_{m1} (mb)	Γ_1 (MeV)	E_{m2} (MeV)	σ_{m2} (mb)	Γ_2 (MeV)			
¹⁸¹ Ta	25.2	3799	2983	2180	790	13 ^{ff}	205	14.8	10.8-18.8	12.30	259	2.43	15.23	341	4.48	688e5	S	143
¹⁸¹ W	21.3	3848	2854	1860	994	0	203	15.0	10.8-18.8	12.56	268	2.66	15.17	328	4.69	75Ve5	S	144
¹⁸⁶ W	28.6	4502	3004	1655	1200	149	203	14.5	10.8-18.8	12.59	211	2.29	14.68	334	5.18	698e8	L	145
¹⁸⁶ Re	21.6	3991	3226	2461	765	0	227	16.6	10.8-18.8	12.63	279	2.77	15.24	375	4.69	75Ve5	S	146
¹⁸⁶ Os	19.7	2964	2501	2038	463		179	13.2	10.8-18.8	13.03	308	3.13	15.26	302	3.38	798e4	L	147
¹⁸⁶ Os	30.4	4731	3616	2616	885	115	239	16.7	10.8-18.8	12.81	260	2.76	14.88	390	4.19	798e4	L	148
¹⁸⁷ Os	29.9	4722	3326	2130	996	200	228	16.7	10.8-18.8	12.68	268	2.71	14.68	355	3.62	798e4	L	149
¹⁸⁷ Os	23.4	4602	3236	2013	1080	142	220	15.8	10.8-18.8	12.68	206	2.60	14.40	401	4.16	798e4	L	150
¹⁹² Os	29.9	4900	3315	1923	1200	192	224	16.0	10.8-18.8	12.68	206	2.49	14.35	389	4.41	798e4	L	151
¹⁹² Ir	21.9	3596	2965	2334	631		211	15.6	11-17	13.80	487	5.08				75Ve5	S	152
¹⁹² Pt	20.3	3575	3056	2537	519		228	17.8	11-17	13.72	512	4.99				75Ve5	S	153
¹⁹⁷ Au	22.0	3000	3000 ^a													62M13	S	
¹⁹⁷ Au	24.7	3744	2967	2190	777 ^k		205	14.7	11-17	13.82	560	3.84				62Fu2	L	154
¹⁹⁷ Au	21.7	3546	3067	2588	479 ⁿ	gg	217	15.9	11-17	13.72	541	4.61				70Ve1	S	155
¹⁹⁷ Au	16.9	2606	2491	2376	116		194	15.6	11-17 ^{jj}	13.73	502	4.76				868e1	L	
¹⁹⁸ Hg	21.1	3678	3133	2588	545	0	227	17.2	11-17	13.72	582	4.39				75Ve5	S	156
²⁰⁸ Pb	26.4	3441	2909	2377	532 ^k		203	15.0	10-17	13.59	514	3.85				64Ha2	L	157
²⁰⁸ Pb	26.4	3267	2718	2169	549 ^k		191	14.2	10-17	13.56	481	3.96				64Ha2	L	158
²⁰⁸ Pb	26.4	3496	2636	1776	860 ^k		189	14.2	10-17	13.46	491	3.90				64Ha2	L	159
²⁰⁸ Pb	18.9	3387	3059	2731	328 ^D	hh	229	17.6	10-17	13.43	639	4.07				70Ve1	S	160
²⁰⁸ Pb	14.9	2090	2090 ^a				165 ^a	13.3 ^a	10-17 ^{jj}	13.63	645	3.94				72Yo	I	161
²⁰⁸ Pb	22.0	4100	4100 ^a													62M13	S	
²⁰⁸ Pb	16.9	3192	3047	2902	145		249	21.1	10-17 ^{jj}	13.48	602	4.20				868e1	L	
²⁰⁹ Bi	22.0	3730	3730 ^a													62M13	S	
²⁰⁹ Bi	26.4	3772	3058	2344	714 ^k		214	15.8	10-17	13.45	521	3.97				64Ha2	L	162
²⁰⁹ Bi	14.8	2129	2129 ^a				170 ^a	13.8 ^a	10-17 ^{jj}	13.56	648	3.72				72Yo	I	163

Nucleus	$E_{\gamma, \text{max}}$ (MeV)	$\sigma_{\text{int}}(\gamma, \text{Sn})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{tot})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{in})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{2n})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{3n})$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, \text{tot})$ (mb)	$\sigma_{\text{int}}(\gamma, \text{tot})$ (mb-MeV ⁻¹)	Fitting Interval (MeV)	Lorentz Parameters						Reference	Laboratory	Figure Number
										ϵ_{m1} (MeV)	σ_{m1} (mb)	Γ_1 (MeV)	ϵ_{m2} (MeV)	σ_{m2} (mb)	Γ_2 (MeV)			
²³² Th	16.3	3888	2705	1730	787	188 ¹¹	228	20.2	9-18 ¹¹	11.26	283	4.32	14.18	306	4.48	73ve1 ^{kk}	S	164
²³² Th	18.3	5606	3483	1663	1450	370 ¹¹	276	22.7	9-18	11.03	302	2.71	13.87	449	4.77	80Ca1 ¹¹	L	165
²³³ U	17.8	9000	3024	580	0	2444 ¹¹	239	19.6	9-18 ¹¹	11.08	221	1.94	13.86	433	5.47	86Be2 ¹¹	L	166
²³³ U	18.3	8676	3317	1055	0	2262 ¹¹	270	23.3	9-18	11.13	371	2.26	13.94	401	4.46	86Be2 ¹¹	L	167
²³⁵ U	18.5		3714	1056	1588	1060 ¹¹	293	24.1	9-16.5	10.58	380	1.77	13.84	531	4.55	u4803 ^{kk}	L	
²³⁵ U	18.3	8889	3497	1135	202	2160 ¹¹	277	22.9	9-18	10.90	328	2.30	13.96	459	4.75	80Ca1 ¹¹	L	168
²³⁶ U	18.3	7168	3156	1256	450	1450 ¹¹	252	20.9	9-18	10.92	271	2.55	13.78	415	4.88	80Ca1 ¹¹	L	169
²³⁷ Np	16.6	7792	2795	1013	121	1661 ¹¹	233	20.5	9-18 ¹¹	11.02	256	2.94	14.11	392	4.71	73ve1 ^{kk}	S	170
²³⁷ Np	18.3	10909	3799	1172	349	2278 ¹¹	298	24.4	9-18	10.98	311	2.17	14.08	540	4.66	86Be2 ¹¹	L	171
²³⁸ U	18.3	6351	3017	1199	899	919 ¹¹	242	20.4	9-18	10.94	296	2.65	14.00	381	4.59	73ve1 ^{kk}	S	172
²³⁸ U	18.3	7465	3575	1358	1132	1085 ¹¹	286	23.9	9-18	10.77	311	2.37	13.80	459	5.13	80Ca1 ¹¹	L	173
²³⁹ Pu	17.8	9806	2930	631	153	2146 ¹¹	235	19.6	9-18 ¹¹	11.28	325	2.48	13.73	384	4.25	86Be2 ¹¹	L	174

Footnotes to the Table

^aNot corrected for ($\gamma, 2n$) events; the figures given are for the photoneutron yield cross section $\sigma[(\gamma, n) + (\gamma, pn) + 2(\gamma, 2n)]$.

^bSome (γ, tot) data up to 30.1 MeV.

^cSome (γ, tot) data up to 29.5 MeV.

^dSome (γ, tot) data up to 26.2 MeV.

^eSome (γ, tot) data up to 22.7 MeV.

^fExtrapolated to 23 MeV.

^gDoes not include (γ, pn) events.

^h12.0 MeV-mb up to 26.4 MeV.

ⁱ508 MeV-mb up to 31.2 MeV.

^jSome ($\gamma, 2n$) data up to 29 MeV.

^kIncludes $(3/2)\sigma_{\text{int}}(\gamma, 3n)$.

^l768 MeV-mb up to 27.4 MeV.

^m742 MeV-mb up to 28.5 MeV.

ⁿ671 MeV-mb up to 27.1 MeV.

^o614 MeV-mb up to 26.3 MeV.

^p $\sigma_{\text{int}}(\gamma, pn)$.

^q $\sigma_{\text{int}}(\gamma, p)$.

^r $\sigma_{\text{int}}(\gamma, pn)$ up to 30.0 MeV.

^s $\sigma_{\text{int}}(\gamma, pn)$ up to 27.8 MeV.

^t3.4 MeV-mb up to 29.2 MeV.

^u22 MeV-mb up to 28.9 MeV.

^v49 MeV-mb up to 28.4 MeV.

^w31 MeV-mb up to 31.2 MeV.

^x13 MeV-mb up to 28.6 MeV.

^ySome ($\gamma, 3n$) data up to 30 MeV.

^z36 MeV-mb up to 33.0 MeV.

aa59 MeV-mb up to 27.4 MeV.

bb46 MeV-mb up to 29.3 MeV.

cc45 MeV-mb up to 28.5 MeV.

dd52 MeV-mb up to 27.7 MeV.

ee65 MeV-mb up to 28.5 MeV.

ff137 MeV-mb up to 36.4 MeV; some $(\gamma, 4n)$ data up to 36.4 MeV.

gg24 MeV-mb up to 27.1 MeV.

hh197 MeV-mb up to 37.8 MeV; some $(\gamma, 4n)$ data up to 37.8 MeV.

ii_oint(γ, f).

jjData do not extend to upper limit of fitting interval.

kk_v(E_γ) estimated.

ll_v(E_γ) measured.

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Explanation of the Graphs of Photoneutron Cross Sections

The graphs presented are listed in the table with relevant figure numbers. Figure B, on the following page, shows, in diagrammatic style, the stable nuclei for which giant-resonance cross-section measurements have been made with monoenergetic photons.

The following designations are used on the graphs:

(a) Photoneutron yield cross section
 $\sigma(\gamma, Sn) = \sigma[(\gamma, 1n) + 2(\gamma, 2n) + 3(\gamma, 3n) + \dots + \sigma(\gamma, f)]$

(b) Total photoneutron cross section
 $\sigma(\gamma, tot) = \sigma[(\gamma, 1n) + (\gamma, 2n) + (\gamma, 3n) + (\gamma, f)]$.

(c) Single photoneutron cross section
 $\sigma(\gamma, 1n) = \sigma[(\gamma, n) + (\gamma, pn)]$.

(d) Double photoneutron cross section
 $\sigma(\gamma, 2n) = \sigma[(\gamma, 2n) + (\gamma, p2n)]$.

(e) Triple photoneutron cross section $\sigma(\gamma, 3n)$. For the nuclei ^{16}O , ^{31}P , ^{32}S , and ^{39}K , part (e) is $\sigma(\gamma, pn)$; for ^{18}O , it is $\sigma(\gamma, p)$; and for the actinide nuclei, it is $\sigma(\gamma, f)$.

Threshold	Indicated on the graphs by arrows; values are taken from
Energies	A. H. Wapstra and K. Bos, Atomic Data and Nuclear Data Tables <u>19</u> , 215 (1977).

References for the data and the laboratories where the measurements were made are listed in the table.

The solid curves, drawn on the graphs of the total photoneutron cross sections for most medium and heavy nuclei, are Lorentz curves fitted to the giant-resonance data, whose parameters are given in the table.

Fig. B. Chart of the stable nuclei, showing those for which giant-resonance cross-section measurements have been performed with monoenergetic photons.

Fig. 1A

Fig. 18

Fig. 2A

Fig. 3A

Integrated Cross Sections

Fig. 38

Fig. 4A

Fig. 48

Fig. 5A

Integrated Cross Sections

Fig. 58

Fig. 6A

Fig. 6B

Fig. 7A

Integrated Cross Sections

Fig. 7B

Fig. 8A

Integrated Cross Sections

Fig. 88

Fig. 9A

Fig. 9B

Fig. 10A

Fig. 10B

Fig. 11A

Fig. 11B

Fig. 12A

Fig. 12B

Fig. 13A

Fig. 13B

Fig. 14A

Fig. 148

Fig. 15A

Integrated Cross Sections

Fig. 158

Fig. 16A

Fig. 168

Fig. 17A

Integrated Cross Sections

Fig. 17B

Fig. 18A

Fig. 188

Fig. 19A

Integrated Cross Sections

Fig. 198

Fig. 20A

Fig. 208

Fig. 21A

Fig. 218

Fig. 22A

Fig. 22B

Fig. 23A

Fig. 238

Fig. 24A

Fig. 24B

Fig. 25A

Fig. 25B

Fig. 2bA

Fig. 26B

Fig. 27A

Integrated Cross Sections

Fig. 278

Fig. 28A

Integrated Cross Sections

Fig. 288

Fig. 29A

Fig. 29B

Fig. 30A

Fig. 308

Fig. 31A

Integrated Cross Sections

Fig. 318

Fig. 32A

Integrated Cross Sections

Fig. 328

Fig. 33A

Fig. 338

Fig. 34A

Fig. 34B

Fig. 35A

Integrated Cross Sections

Fig. 358

Fig. 36A

Fig. 368

Fig. 37A

Fig. 378

Fig. 38A

Integrated Cross Sections

Fig. 388

Fig. 39A

Integrated Cross Sections

Fig. 398

Fig. 40A

Fig. 40B

Fig. 41A

Fig. 41A

Fig. 41B

Fig. 42A

Integrated Cross Sections

Fig. 42B

Fig. 43A

Fig. 43B

Fig. 44A

Fig. 44B

Fig. 45A

Fig. 45B

Fig. 46A

Fig. 468

Fig. 47A

Fig. 47B

Cross Section (mb)

Cross Section (mb)

Cross Section (mb)

Cross Section (mb)

Fig. 48A

Fig. 488

Fig. 49A

Fig. 49B

Fig. 50A

Fig. 50B

Fig. 51A

Fig. 518

Fig. 52A

Fig. 52B

Fig. 53A

Fig. 53B

Fig. 54A

Integrated Cross Sections

Fig. 54B

Fig. 55A

Fig. 55B

Fig. 56A

Fig. 56B

Fig. 57A

Fig. 57B

Fig. 58A

Fig. 58B

Fig. 59A

Fig. 59B

Fig. 60A

Fig. 60B

Fig. 61A

Fig. 618

Fig. 62A

Fig. 62B

Fig. 63A

Fig. 63B

Fig. 64A

Fig. 648

Fig. 65A

Fig. 658

Fig. 66A

Fig. 66B

Fig. 67A

Fig. 67B

Fig. 68A

Fig. 688

Fig. 69A

Fig. 69B

Fig. 70A

Integrated Cross Sections

Fig. 708

Fig. 71A

Fig. 71B

Fig. 72A

Fig. 72B

Fig. 73A

Fig. 73D

Fig. 74A

Fig. 748

Fig. 75A

Fig. 75B

Fig. 76A

Fig. 76B

Fig. 77A

Integrated Cross Sections

Fig. 778

Fig. 78A

Fig. 78B

Fig. /98

Fig. 80A

Fig. 80B

Fig. 81A

Fig. 81B

Fig. 82A

Fig. 82B

Fig. 83A

Integrated Cross Sections

Fig. 83B

Fig. 84A

Fig. 848

Fig. 85A

Fig. 85B

Fig. 86A

Fig. 86B

Fig. 87A

Fig. 87B

Fig. 88A

Fig. 8BB

Fig. 89A

Fig. 89B

Fig. 90A

Fig. 90B

Fig. 91A

Integrated Cross Sections

Fig. 92B

Fig. 92A

Fig. 92B

Fig. 93A

Fig. 93B

Fig. 94A

Fig. 948

Fig. 95A

Fig. 958

Fig. 96A

Fig. 968

Fig. 97A

Fig. 97B

Fig. 98A

Fig. 98B

Fig. 99A

Fig. 99B

Fig. 100A

Fig. 100B

Fig. 101A

Fig. 101B

Fig. 102A

Fig. 102B

Fig. 103A

Fig. 103B

Fig. 104A

Fig. 104B

Fig. 105A

Fig. 1058

Fig. 106A

Fig. 1068

Fig. 107A

Fig. 107B

Fig. 108A

Fig. 10BB

Fig. 109A

Fig. 109B

Fig. 110A

Fig. 110B

Fig. 111A

Fig. 1118

Fig. 112A

Fig. 112B

Fig. 113A

Fig. 113B

Fig. 114A

Fig. 114B

Fig. 115A

Fig. 115B

Fig. 116A

Fig. 116B

Fig. 117A

Fig. 117B

Fig. 118A

Fig. 118B

Fig. 119A

Fig. 119B

Fig. 120A

Fig. 1208

Fig. 121A

Integrated Cross Sections

Fig. 121B

Fig. 122A

Fig. 122B

Fig. 123A

Fig. 123B

Fig. 124A

Integrated Cross Sections

Fig. 124B

Fig. 125A

Fig. 125B

Fig. 126A

Fig. 126B

Fig. 127A

Fig. 127B

Fig. 128A

Fig. 128B

Fig. 129A

Fig. 129B

Fig. 130A

Fig. 1308

Fig. 131A

Fig. 131B

Fig. 132A

Fig. 132B

Fig. 133A

Fig. 133B

Fig. 134A

Fig. 134B

Fig. 135A

Fig. 135B

Fig. 136A

Fig. 1368

Fig. 137A

Fig. 137B

Fig. 138A

Fig. 138B

Fig. 139A

Fig. 139B

Fig. 140A

Fig. 1408

Fig. 141A

Fig. 141B

Fig. 142A

Fig. 142B

Fig. 143A

Fig. 143B

Fig. 144A

Fig. 144B

Fig. 145A

Fig. 145B

Fig. 146A

Fig. 146B

Fig. 147A

Fig. 147B

Fig. 148A

Fig. 1488

Fig. 149A

Fig. 1498

Fig. 150A

Fig. 150B

Fig. 151A

Fig. 151B

Fig. 152A

Integrated Cross Sections

Fig. 1528

Fig. 153A

Fig. 153B

Fig. 154A

Fig. 154B

Fig. 155A

Fig. 155B

Fig. 156A

Fig. 156B

Fig. 157A

Fig. 157B

Fig. 158A

Fig. 158B

Fig. 159A

Fig. 159B

Fig. 160A

Fig. 160B

Fig. 161A

Fig. 161B

Fig. 162A

Fig. 162B

Fig. 163A

Fig. 163B

Fig. 164A

Fig. 1648

Fig. 165A

Fig. 165B

Fig. 166A

Fig. 166B

Fig. 167A

Fig. 167B

Fig. 168A

Fig. 168B

Fig. 169A

Fig. 169B

Fig. 170A

Fig. 1708

Fig. 171A

Fig. 171B

Fig. 172A

Fig. 1728

Fig. 173A

Fig. 173B

Fig. 174A

Fig. 28

Fig. 1748