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Total Gamma-Ray Cross Sections in the Energy Region 60–1400 keV

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Total γ-ray cross sections at 12 γ energies (most of them are at new energies) are determined in Cu, W, and Pb and the results are reported. The error in these results is of the order of 1%. An analysis of the data is presented.

I. INTRODUCTION

In previous investigations,[1,2] it was shown that there are inconsistencies in the available total γ-ray experimental cross sections. Recently a few measurements were reported.[3,4] However, there remain large energy gaps, especially above 145 keV. Hence, in the present investigations these cross sections are measured at 12 γ energies (most of them are at new energies) in a wide energy region from 60 to 1400 keV in three typical elements, viz., Cu, W, and Pb, and the results are reported.

II. EXPERIMENTAL DETAILS AND RESULTS

The total γ-ray cross sections can be measured by conducting the usual transmission experiment[3–6] on a good geometry setup. A similar[3–6] good

TABLE I. Table of isotopes.

Serial No.	Isotope	Energy (keV)
1	^{241}Am	60
2	^{144}Ce	133
3	^{177}Lu	208
4	^{51}Cr	320
5	^{133}Ba	355 (300 16%, 360 70%, 380 10%)
6	^{75}Se	400
7	^{85}Sr	513
8	^{95}Zr	743 (760 45%, 730 55%)
9	^{134}Cs	800
10	^{54}Mn	840
11	^{22}Na	1280
12	^{152}Eu	1400

geometry setup with a 2.5×2.5-in. NaI(Tl) crystal-mounted 6292 photomuliplier and a single-channel analyzer are used in the present investigations. The elements used are in the form of foils and rods of $\frac{5}{8}$ in. diam with various thicknesses. The γ-ray sources and the selected energies that were used are listed in Table I. In two cases where the energies are not resolvable perfectly, the weighted average of the energies is taken. Experiments are conducted so that the transmission varies from 0.30 to 0.7. A statistical error of less than 0.5% is maintained throughout. The total γ-ray cross sections are estimated by the method of least squares as given by

$$\mu_a = \frac{\log_e 10 \; \sum_{r=1}^{k} (X_r \log_{10} N_0/N_r)}{\sum_{r=1}^{k} X_r^2} \frac{A}{NP} \cdots, \tag{1}$$

where μ_a is the atomic cross section, X_r is the thickness of the absorber, N_0 is the intensity without absorber, N_r is the intensity with the absorber of thickness X_r, A is the atomic weight, N is Avogadro's number, P is the density of the element (absorbers), and K is the number of absorbers. The entire experiment for each set of absorbers is repeated four to six times and the average values are taken. After correcting for the effects of scattering and the higher γ energies, if any, we compiled the results, along with the theoretical values of Storm and Isreal,[7] in Table II. The error in the total cross sections is of the order of 1%.

TABLE II. Total γ interaction cross sections in barns per atom.

Serial No.	Energy (keV)		Cu	W	Pb
1	60	Expt.	166		1660
		Theor.	167		1700
2	133	Expt.	28		
		Theor.	28		
3	208	Expt.	14.9	216.8	301.3
		Theor.	15.6	217.5	302.0
4	320	Expt.	10.8	81	113
		Theor.	11.2	83	117
5	355	Expt.	10.2	66.1	98.6
		Theor.	10.6	68.0	100.0
6	400	Expt.	9.9	58.0	78.6
		Theor.	9.9	58.1	78.8
7	513	Expt.	8.6	40.0	52.2
		Theor.	8.65	40.1	52.6
8	743	Expt.	7.1	26.0	29.9
		Theor.	7.25	26.1	32.4
9	800	Expt.	6.5	23.2	30.0
		Theor.	6.95	24.4	30.1
10	840	Expt.	6.4	23.1	28.3
		Theor.	6.8	23.4	28.6
11	1280	Expt.	5.4	16.4	19.5
		Theor.	5.5	16.7	19.8
12	1400	Expt.	5.04	15.8	17.9
		Theor.	5.24	15.9	18.6

TABLE III. Total photoelectric cross sections in barns per atom (2–5% error).

Serial No.	Energy (keV)		Cu	W	Pb
1	60	Expt.	141		1461
		Theor.	142		1500
2	208	Expt.		175.8	253
		Theor.		174.0	252
3	320	Expt.		50.5	78.2
		Theor.		51	85
4	355	Expt.		37.4	66
		Theor.		38	67
5	400	Expt.		31.4	48.5
		Theor.		31.5	48.7
6	513	Expt.		16.9	26.2
		Theor.		17.0	26.4
7	800	Expt.			9.7
		Theor.			9.86

TABLE IV. Total-to-shell ratios.

Element	Total/ K shell	Total/L shell below K edge	Total/L shell above K edge	Total/M shell below K edge	Total/M shell above K edge
Cu	1.13	···	···	···	···
W	1.2	···	···	···	···
Pb	1.22	1.29 ± 5%	6.61 ± 6%	5.61 ± 14%	27.65 ± 15%

TABLE V. K-shell photoelectric cross sections in barns per atom (error: 3–6%).

Serial No.	Energy (keV)		Cu	W	Pb
1	60	Expt.	124		
		Theor.	127		
2	208	Expt.		146.5	207.3
		Theor.		144	208
3	320	Expt.		42.1	64.1
		Theor.		45.5	68
4	355	Expt.		31.2	54
		Theor.		35.0	53.9
5	400	Expt.		26.2	39.8
		Theor.		26.2	39.8
6	513	Expt.		14.1	21.5
		Theor.		14.2	21.9
7	800	Expt.			7.9
		Theor.			8.11

TABLE VI. Shellwise photoelectric cross sections in Pb in barns per atom. Error: L shell (5-10%); M shell (15-16%).

Serial No.	Energy (keV)		L shell	M shell
1	60	Expt.	1130	260
		Theor.	1160	292
2	208	Expt.	38	9.2
		Theor.	38	9.2
3	320	Expt.	11.8	2.8
		Theor.	12	3
4	355	Expt.	9.9	2.3
		Theor.	9.3	2.3
5	400	Expt.	7.4	1.75
		Theor.	6.76	1.64
6	513	Expt.	3.9	0.95
		Theor.	3.7	0.88
7	800	Expt.		0.35
		Theor.		0.32

III. DISCUSSION

It can be seen from Table II that the agreement between theory and experiment is within 10%. The photoelectric cross sections obtained by subtracting the other theoretical partial cross sections[7] from the total γ-ray cross sections at low energies, along with the theoretical photoelectric cross sections of Schmickley and Pratt,[8] are given in Table III. Similarly, the K-shell cross sections in Cu, W, and Pb, and L- and M-shell cross sections in Pb, obtained by dividing the total photoelectric cross section with the ratio,[9] total to shell (given in Table IV), along with the theoretical values of Schmickley and Pratt,[8] are given in Tables V and VI, respectively. From Tables V and VI it can be seen that the agreement between theory and experiment is in general satisfactory to within a few percent.

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