Photoelectric cross sections for 72.1-keV x rays in Al, Cu, Zr, Ag, Sn, Ta, Au, and Pb derived from a total attenuation-coefficient measurement

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The photoelectric cross sections have been extracted from the total absorption cross sections. The total cross sections have been estimated by measuring the absorption in Al, Cu, Zr, Ag, Sn, Ta, Au, and Pb for 72.1-keV x rays resulting from the decay of ^{203}Hg. The scattering cross sections are taken from recent tabulated values of Veigele for subtraction purposes. The photoelectric cross sections are compared with the values interpolated from the theoretical results of (i) Schmickley and Pratt and (ii) Scofield.

I. INTRODUCTION

The photoelectric cross sections are measured in two ways: (i) direct measurements and (ii) indirect measurements. In the direct measurements the photoelectrons are estimated using magnetic spectrometer or scintillation spectrometers. A number of authors[1-11] have measured the photoelectric cross sections using the spectrometers above 100 keV. In the indirect method the total cross sections are measured and the scattering cross sections are subtracted from them to get the photoelectric cross sections. Such measurements are available both above and below 100 keV.[12-14] Agreement between the experimental and the theoretically predicted values is good at higher energies, but as the K-shell threshold is approached the disagreement becomes 10% and even more.[15,16]

In the low-energy region the direct measurements are difficult to make. The self-absorption in the converter foil becomes large. It is also difficult to procure sufficiently strong sources. Below 100 keV in medium- and high-Z materials, the photoelectric cross sections are very high compared to scattering cross sections; therefore, the subtraction procedure for determining the photoelectric cross section is justified. With this end in view, the total cross sections are measured for 72.1-keV x rays in Al, Cu, Zr, Ag, Sn, Ta, Au, and Pb. The scattering cross sections taken from Veigele[17] have been subtracted from the total cross sections to get the photoelectric cross sections. The photoelectric cross sections are compared with the values interpolated from theoretical results of (i) Schmickley and Pratt[18] and (ii) Scofield.[19]

II. EXPERIMENTAL METHOD

The experimental setup that provides the required good-geometry condition is shown schematically in Fig. 1. The ^{203}Hg source (15 mCi, obtained from Bhabha Atomic Research Centre, Bombay, India) is used to get 72.1-keV x rays. The 72.1-keV energy is the mean of the thallium K x rays [$\frac{2}{3}$ Tl $K\alpha_1$(72.87 keV) + $\frac{1}{3}$ Tl $K\alpha_2$(70.83 keV) = 72.19 keV] from the residual atom. Hence the 72.1-keV x ray peak is pure except for the bremsstrahlung, due to the low-energy β particles, which is very small. The detector is a 3.8-cm-diam by 0.6-cm-thick NaI (Tl) crystal covered by a 0.012-cm beryllium foil. The counter is 100% efficient in this energy region. The crystal is mounted on a RCA 6292 photomultiplier tube, the pulses from which are amplified and fed through a single-channel analyzer to a preset time scaler. The experiment is performed in an air-conditioned room. The main voltage is also stabilized. The drift in

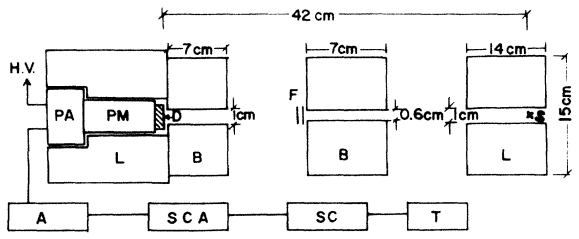

FIG. 1. Schematic diagram of experimental setup: S–source; L–lead shielding; B–lead collimator; F–sample holder; D–NaI(Tl) crystal; PM–photomultiplier; PA–preamplifier; A–amplifier; SCA–single-channel analyzer; SC– scaler; T–timer; HV–high-tension power supply.

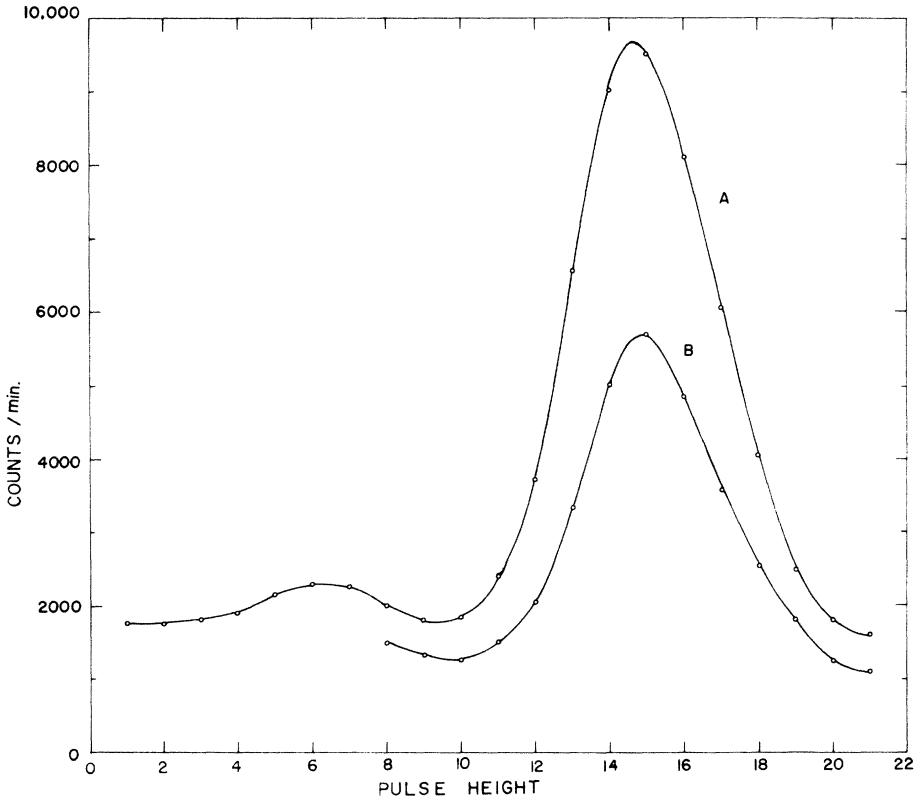

FIG. 2. Typical pulse-height spectra of 72.1-keV x rays: (A) without any absorber; (B) with lead absorber (t = 210 mg/cm^2).

the spectrometer gain is negligable. The samples of Al, Cu, Zr, Ag, Sn, Ta, Au, and Pb in the form of circular foils of 1.5 cm diameter are used. The purity of the target materials is better than 99.6%. Each foil has uniform thickness, and the thicknesses chosen are in the range from 50 to 800 mg/cm^2. The individual thicknesses also vary from element to element.

III. PROCEDURE

The photo peaks of 72.1-keV x rays are recorded with and without samples of different thicknesses t and the plots of pulse-height distributions are drawn (Fig. 2). The corrections for the Compton-scattered photons from the 279-keV γ photons are made. From the areas under these peaks, the number of photons transmitted is estimated. The number of transmitted photons through the different absorber foils is plotted on semilog paper and its slope gives the attenuation coefficient μ. The thicknesses are chosen such that the criterion $\mu t < 1$ established by Gopal and Sanjeevaiah[20] is satisfied. In the present investigations, generally the μt values are less than 0.6. Also for each of these thicknesses, attenuation coefficients are determined by following the counting sequence of

TABLE I. Attenuation coefficients in cm^2/gm.

Element	Transmission method	Selecting the window of 20 keV	$10^{24}\,N/A$
Al	0.2147 ± 0.0044	0.2173 ± 0.0044	0.022 32
Cu	0.9963 ± 0.0189	0.9951 ± 0.0189	0.009 478
Zr	2.2400 ± 0.0462	2.2710 ± 0.0462	0.006 602
Ag	3.4402 ± 0.0725	3.4949 ± 0.0725	0.005 583
Sn	3.9045 ± 0.0811	3.9475 ± 0.0811	0.005 074
Ta	10.4665 ± 0.2196	10.4865 ± 0.2196	0.003 328
Au	5.5690 ± 0.0611	5.5912 ± 0.0611	0.003 058
Pb	3.2662 ± 0.0668	3.2674 ± 0.0668	0.002 907

TABLE II. Total cross sections in b/atom.

Element	Present	McCrary *et al.* (Ref. 21)
Al	9.76 ± 0.2	9.58 ± 0.06
Cu	105 ± 2	104 ± 0.3
Zr	344 ± 7	341 ± 0.6
Ag	626 ± 13	622 ± 4
Sn	778 ± 16	774 ± 5
Ta	3151 ± 66	...
Au	964 ± 20	872 ± 5
Pb	1124 ± 23	1039 ± 5

TABLE III. Scattering cross sections in b/atom [Veigele (Ref. 17)].

Element	Coherent	Incoherent
Al	1.12	6.42
Cu	10.4	11.6
Zr	19.5	18.5
Ag	28.7	21.3
Sn	33.7	22.3
Ta	89.8	31.2
Au	110.0	33.0
Pb	118.0	34.0

TABLE IV. Photoelectric cross sections in b/atom.

Element	Present	Schmickley and Pratt (Ref. 18)	Scofield (Ref. 19) 72.1 keV	Scofield (Ref. 19) 70.2 keV
Al	2.22 ± 0.2	2.3	2.32	2.53
Cu	83 ± 2	82	81	88
Zr	306 ± 7	300	300	325
Ag	576 ± 13	578	570	610
Sn	722 ± 16	728	720	780
Ta	3030 ± 66	2830	2830	3050
Au	821 ± 20	785	780	830
Pb	972 ± 23	932	920	980

McCrary *et al.*[21] and selecting the 20-keV gate around the photo peak.

IV. RESULTS AND DISCUSSION

The measured attenuation coefficients by both methods are given in Table I and are found to be the same within the experimental errors. For further calculations the values in the second column are used. In this table N/A values (N is the Avogadro number and A is the atomic weight of the element) for the elements used in this experiment are also given. The total cross sections are calculated by dividing the attenuation coefficients by N/A. These results are listed in Table II and compared with those obtained from interpolation of the experimental values of McCrary *et al.* The errors given in Table II are mainly owing to counting statistics, since the sample impurity corrections are negligible. There is good agreement between the two within experimental errors in all cases except in Au and Pb. The scattering cross sections (coherent plus incoherent) are obtained by interpolation from the atomic data compiled by Veigele and are given in Table III. The photoelectric cross sections are then obtained by subtracting the scattering cross sections from the total cross sections. These photoelectric cross sections are given in Table IV and are compared with the values interpolated from the theoretical results of (i) Schmickley and Pratt and (ii) Scofield. There is good agreement within the experimental error except in Ta, Au, and Pb. Our cross sections for Ta, Au, and Pb are high, whereas the photoelectric cross sections estimated from the total cross sections of McCrary *et al.* for Au and Pb are low. The disagreement between the theoretically predicted values and our experimental values is less than 5% in Au and Pb and about 7% in the case of Ta. In Table IV the values interpolated from the results of Scofield for the Hg($K\bar{\alpha}$) x rays (70.2 keV) are also listed. There is agreement between these and our experimental values for Ta, Au, and Pb. This may probably raise the question of source purity, since the 279-keV γ rays also present in the source are capable of exiting Hg($K\bar{\alpha}$) x rays by the external conversion and Compton interactions with relative intensity dependent on source thickness. However, the source thickness is of the order of 0.1 mm and hence the presence of the 70.2-keV x rays is negligible ($< 2\%$). The justification for assuming that the contribution to the photoelectric cross sections from 70.2-keV x rays is negligible also comes from the fact that the observed cross sections in the case of Al, Cu, Zr, Ag, and Sn agree very well with the values interpolated from the results of Scofield for 72.1-keV x rays, whereas there is a discrepancy when compared with the values interpolated at 70.2 keV. These considerations imply that the deviations observed in the case of Ta, Au, and Pb are probaly due to inaccurate estimation of theoretical cross sections near K-edge threshold.

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