K-shell photoelectric cross sections of Cu, Zr, Ag, Sn, Ta, Au, and Pb for 279.1- and 411.8-keV γ rays.

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Measurements of K-shell photoelectric cross sections of copper, zirconium, silver, tin, tantalum, gold, and lead for 279.1- and 411.8-keV γ rays have been carried out using a well-type plastic scintillation spectrometer. The number of K-shell photoelectrons in each material is estimated by fitting a Gaussian to the respective resolved photoelectron spectrum, and hence the K-shell photoelectric cross sections are estimated. This method is similar to the one used for determining the K-shell photoelectric cross sections for 145-keV γ rays which have been reported in an earlier paper by the authors. Also in the present investigation the cross sections are found to be in good agreement with the predicted values of Schmickley and Pratt, and the recently calculated values of Scofield at both energies.

I. INTRODUCTION

The K-shell photoelectric cross sections have been determined experimentally by few authors.[1-8] Ghumman *et al.*[6] estimated the K-shell photoelectric cross sections for 280- and 662-keV γ rays in tin, tungsten, gold, and lead from measured intensities of K-shell fluorescent radiation that follow the emission of the K-shell electron in the interaction. There is disagreement between their experimental values and the predicted values of Schmickley and Pratt.[9] We have not seen in published literature any direct experimental determination of K-shell photoelectric cross sections for 411.8-keV γ rays except the work of Marty,[10] Hultberg[11] and Bergkvist,[12] who reported the total to K-shell, K-shell to L-shell, and the L-subshell ratios at this energy. We reported[8] K-shell photoelectric cross sections for 145-keV γ rays in zirconium, silver, tin, tantalum, and lead measured by using a well-type plastic scintillation spectrometer. The cross sections were found to be in good agreement with the predicted values of Schmickley and Pratt.[9] In the present paper we are reporting the experimental determination of K-shell photoelectric cross sections of copper, zirconium, silver, tin, tantalum, gold, and lead for 279.1- and 411.8-keV γ rays using the same method.[8] The cross sections are compared with the predicted values of Schmickley and Pratt[9] and also with the recent calculations of Scofield.[13]

II. EXPERIMENTAL

The experimental setup used in the present investigation is the same as that described by the authors earlier.[8] The γ-ray sources, 20-mCi ^{203}Hg (279.1 keV) and 100-mCi ^{198}Au (411.8 keV) in the form of radiographic capsules obtained from Bhabha Atomic Research Center, Bombay, India, have been used.

Thin converter foils of mass 8.1, 9.27, 7.65, 9.8, 9.1, 12.0, 13.09, and 8.05 mg/cm^2 of aluminum, copper, zirconium, silver, tin, tantalum, gold, and lead, respectively, of high purity (99.9%) are used. Each converter foil has the same diameter as that of the well of the plastic scintillator.

The γ-background spectrum and the spectra with aluminum, copper, zirconium, silver, tin, tantalum, gold, and lead converter foils are recorded. Typical pulse-height spectra for the γ background and with the aluminum converter are given in Figs. 1(a) and 1(b) for 279.1- and 411.8-keV γ rays, respectively. The γ-background spectrum is subtracted from each of the other spectra to obtain the electron spectrum in that converter. Since the photoelectric contribution is very small in aluminum at these energies, the electron spectrum obtained with aluminum is assumed to be purely the Compton continuum. The Compton continuum in aluminum is used to subtract the Compton contribution in all other converter materials. For the purpose of subtraction the continuum in aluminum is normalized to the number of electrons present in other materials. The typical electron spectra obtained with aluminum and lead converters are given in Figs. 2(a) and 2(b) for both the energies. The resolved photoelectron spectra thus obtained are plotted and the Gaussians are fit to the main peak using the left portion of the photoelectron peak. The areas under these Gaussians would then give the respective number of K-shell photoelectrons. The typical photoelectron spectra in the case of lead are given in Figs. 3(a) and 3(b) for both the energies. The estimated

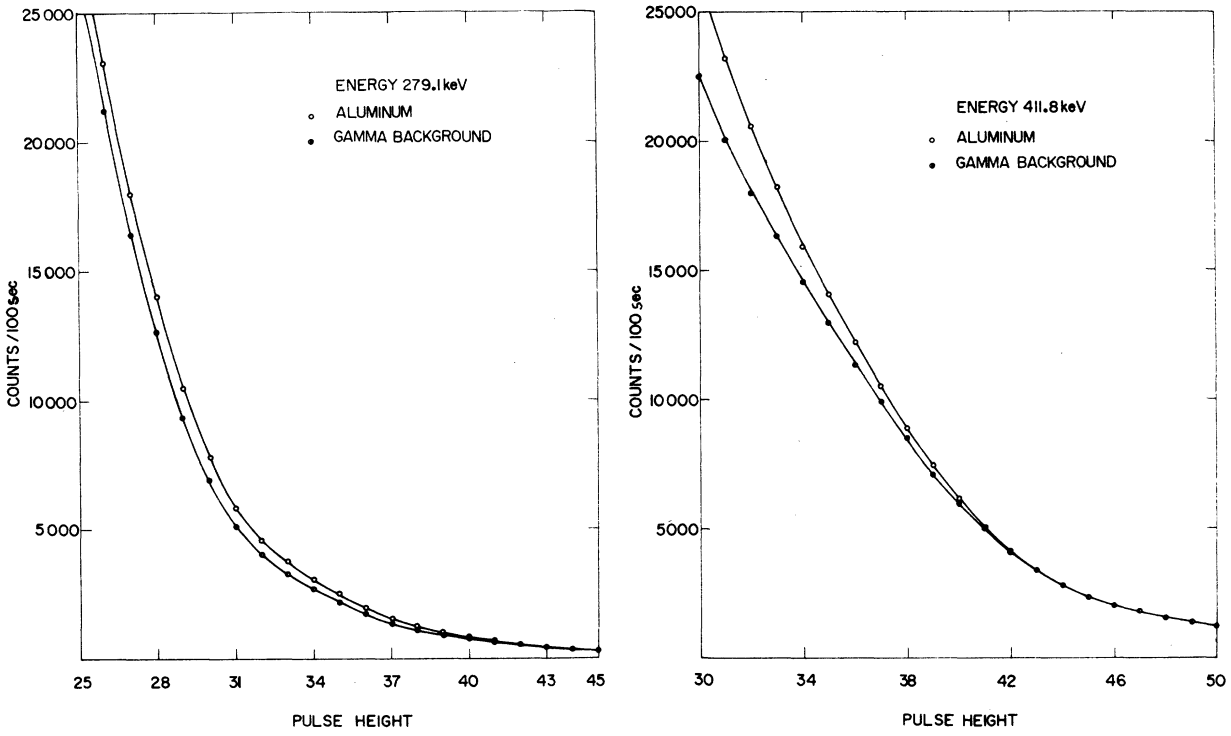

FIG. 1. Typical pulse-height spectra.

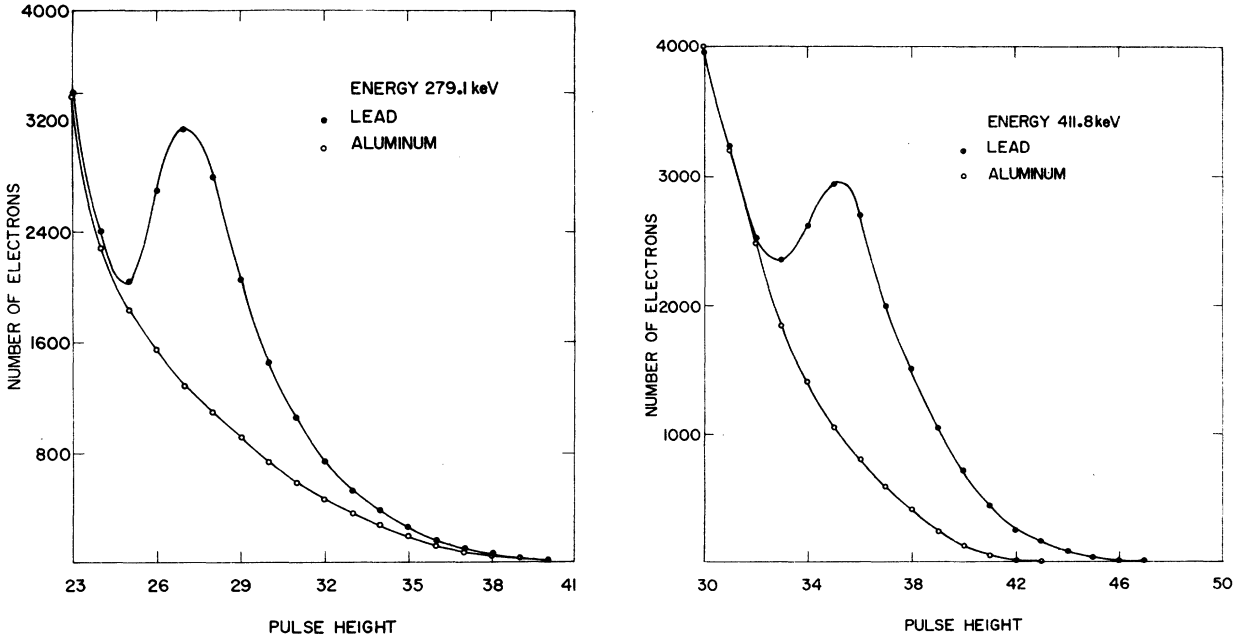

FIG. 2. Resolved electron spectra.

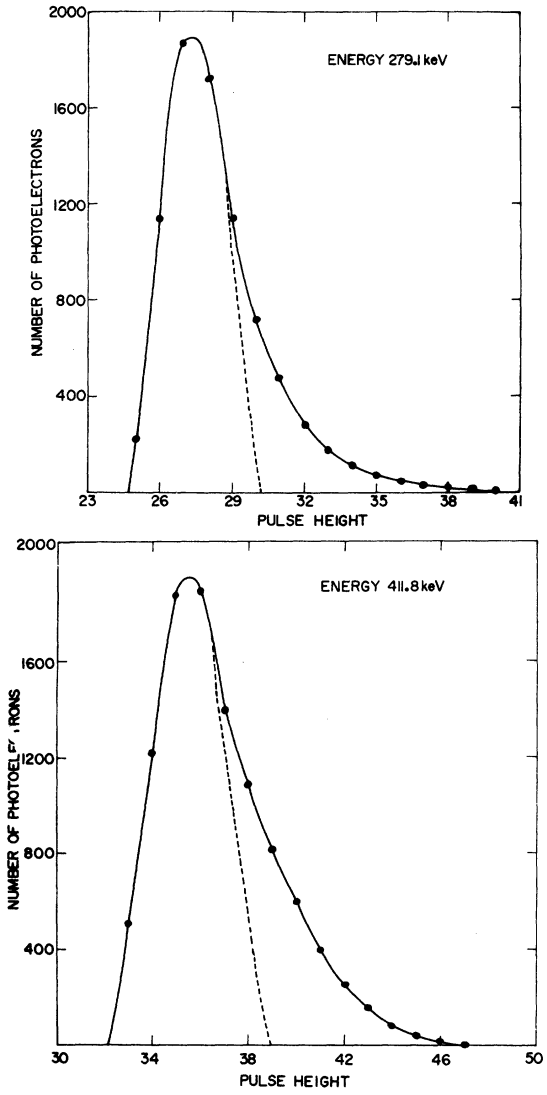

FIG. 3. Resolved photoelectron spectrum of lead (area under the Gaussian fitted to the spectrum gives the number of K-shell photoelectrons).

TABLE I. K-shell photoelectric cross sections for 279.1-keV γ rays (b/atom).

Converter material	Present	Schmickley and Pratt[a]	Scofield[b]
Copper	1.20±0.07	1.22	1.22
Zirconium	5.0±0.2	5.2	5.1
Silver	10.0±0.4	10.2	10.0
Tin	13.0±0.5	13.3	13.2
Tantalum	61.0±3.0	61.6	60.5
Gold	83.0±3.5	85.9	85.0
Lead	100.0±4.0	98.9	99.0

[a]Reference 9.
[b]Reference 13.

TABLE II. K-shell photoelectric cross sections for 411.8-keV γ rays (b/atom).

Converter material	Present	Schmickley and Pratt[a]	Scofield[b]
Copper	0.392±0.019	0.405	0.40
Zirconium	1.60±0.056	1.62	1.6
Silver	3.48±0.14	3.51	3.5
Tin	4.56±0.18	4.61	4.6
Tantalum	22.06±0.88	22.5	22.2
Gold	31.16±1.25	31.8	31.8
Lead	36.33±1.45	37.0	37.0

[a]Reference 9.
[b]Reference 13.

number of K-shell photoelectrons are corrected for self-absorption. This corrected number is used to calculate the K-shell photoelectric cross sections.

The number of atoms exposed to the γ rays is estimated by weighing the experimental converter

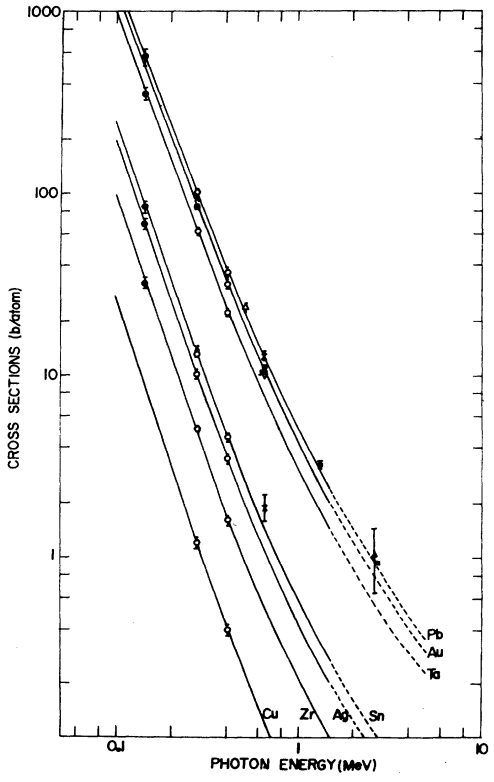

FIG. 4. Plot of K-shell photoelectric cross sections as functions of energy. ●, Ramakrishna Gowda and B. Sanjeevaiah (Ref. 8); ○, present work; X, Ghumman *et al.* (Ref. 6); △, Seeman (Ref. 2); ▽, DiLazzaro and Missoni (Ref. 5); ■, Bleeker *et al.* (Ref. 4); ▲, Davidson and Latyshev (Ref. 1) (the cross section for Pb as given in Ref. 9); ——-, Scofield (Ref. 13); ----, Schmickley and Pratt (Ref. 9).

foil in an electrical balance to an accuracy of 0.001 mg. The number of photons incident on the converter foil is estimated by recording the γ-ray spectra of 279.1 and 411.8 keV using the NaI(Tl) crystal spectrometer in the manner reported earlier.[8]

III. RESULTS AND DISCUSSION

The K-shell photoelectric cross sections are calculated and listed in Tables I and II. The errors associated with the experimental cross sections depend mainly on the statistical uncertainties in the estimated Compton continuum and the number of K-shell photoelectrons beneath the peak and the subtraction procedure. The errors in the estimation of the number of atoms in the converter material and the number of photons are less than 1% and are therefore neglected. The source ^{198}Au emits two γ rays of higher energy in addition to the 411.8-keV γ ray used in the measurements. These γ rays are emitted at 676 keV (1%) and 1088 keV (0.2%). The Compton contribution due to these γ rays to the photoelectron peak area is very small and it is neglected. There is a small photoelectric contribution to the observed electron spectrum with the aluminum converter, and the errors on the calculated cross sections owing to this are found to be about 2.3% in copper and less than 0.4% in all other converter materials at both the energies. These errors are within the statistical uncertainties. So the errors given in the tables are mainly due to statistical uncertainties. The measured cross sections are compared with the theoretical values of Schmickley and Pratt[9] and Scofield.[13] In Fig. 4, the authors and all referenced experimental K-shell cross sections are graphically represented as functions of energy for each element used in the present investigation and these are compared with the theoretical values of Scofield[13] up to 1.5 MeV and with those of Schmickley and Pratt[9] above 1.5 MeV. It can be seen that there is good agreement between our measured values and the predicted values within the experimental errors.

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