K-Shell Photoelectric Cross Sections for 145-keV Gamma Rays

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The spectra of electrons resulting from the interaction of 145-keV γ rays with Zr, Ag, Sn, Ta, and Pb have been obtained using a well-type plastic-scintillation spectrometer. The number of K-shell photoelectrons in each case is estimated by fitting a Gaussian to the respective resolved photoelectron spectrum, and hence the K-shell photoelectric cross sections are estimated. They are found to be 32 ± 2, 68 ± 4, 83 ± 5, 348 ± 21, and 537 ± 32 b/atom, respectively. These values are in good agreement with the interpolated values of Schmickley and Pratt.

I. INTRODUCTION

Although a large amount of work has been done in measuring K-shell photoelectric cross sections, presently available data still contain errors and inconsistencies. Experimental determinations of K-shell cross sections using the β-ray spectrometers have been made by Latyshev,[1] Seeman,[2] Hultberg and Stockendal,[3] Bleeker *et al.*,[4] Bergkvist,[5] and Missoni.[6] The predicted values of Schmickley and Pratt[7] are too small for the data of Seeman,[2] Hultberg and Stockendal,[3] and Bleeker *et al.*[4] There are no experimental data of K-shell photoelectric cross sections for elements of atomic number lower than $Z = 79$ at 145 keV. As the atomic number decreases, the production of photoelectrons decreases. Owing to the poor transmission in the magnetic spectrometer, counting statistics suffer. Stronger γ-ray sources are required to increase the production of photoelectrons. However, it is very difficult to get such strong sources at low energies. It is therefore desirable to use a plastic-scintillation spectrometer to determine the K-shell photoelectric cross sections at low energies in different materials.

The spectra of electrons resulting from the interaction of 145-keV γ rays with Zr, Ag, Sn, Ta, and Pb have been obtained using a well-type plastic-scintillation spectrometer. This method of measurement involves the detection, in a very nearly 4π geometry, of the photoelectrons released from the converter foil. Since the K-shell contribution is predominant, the observed peak in the photoelectron spectrum can be attributed to the K-shell photoelectrons. The number of K-shell photoelectrons in each case is estimated by fitting a Gaussian to the respective peak in the photoelectron spectrum and hence the K-shell photoelectric cross section is estimated. The measured cross sections are compared with the predicted values of Schmickley and Pratt.[7]

II. EXPERIMENTAL DETAILS

The experimental setup is shown in Fig. 1. A 60-mCi Ce^{141} source in the form of a radiographic capsule yielding 145-keV γ rays was obtained from Bhabha Atomic Research Centre, Bombay, India. It was housed in a lead cylinder with a collimating hole of 8 mm in diameter and 70 mm in length. The radiation leaving this collimator passed through another collimator of 6-mm-diam hole and 70 mm in length, and then traversed 12-mm depth and 7-mm-diam well in a 15-mm-thick and 28-mm-diam plastic scintillator (NE-102). The plastic scintillator was optically coupled to an RCA 6199 photomultiplier. The scintillator was covered with a thin aluminum foil except at the top of the

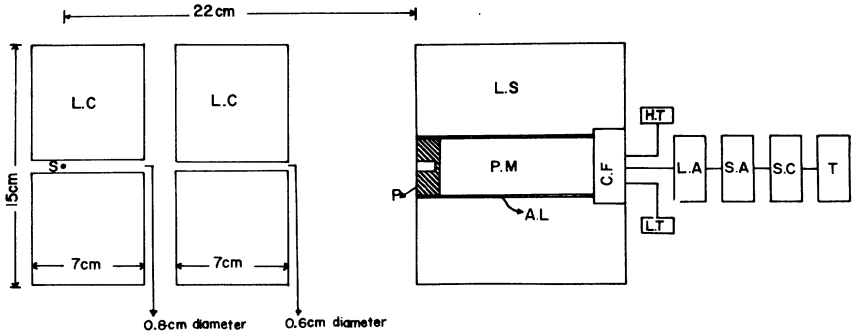

FIG. 1. Schematic diagram of experimental setup. S, source; LC, lead collimators; LS, lead shielding; P, plastic scintillator; PM, photomultiplier; Al, aluminum lining; CF, cathode follower; HT, high-tension power supply; LT, low-tension power supply; LA, linear amplifier; SA, single-channel analyzer; SC, scaler; and T, timer.

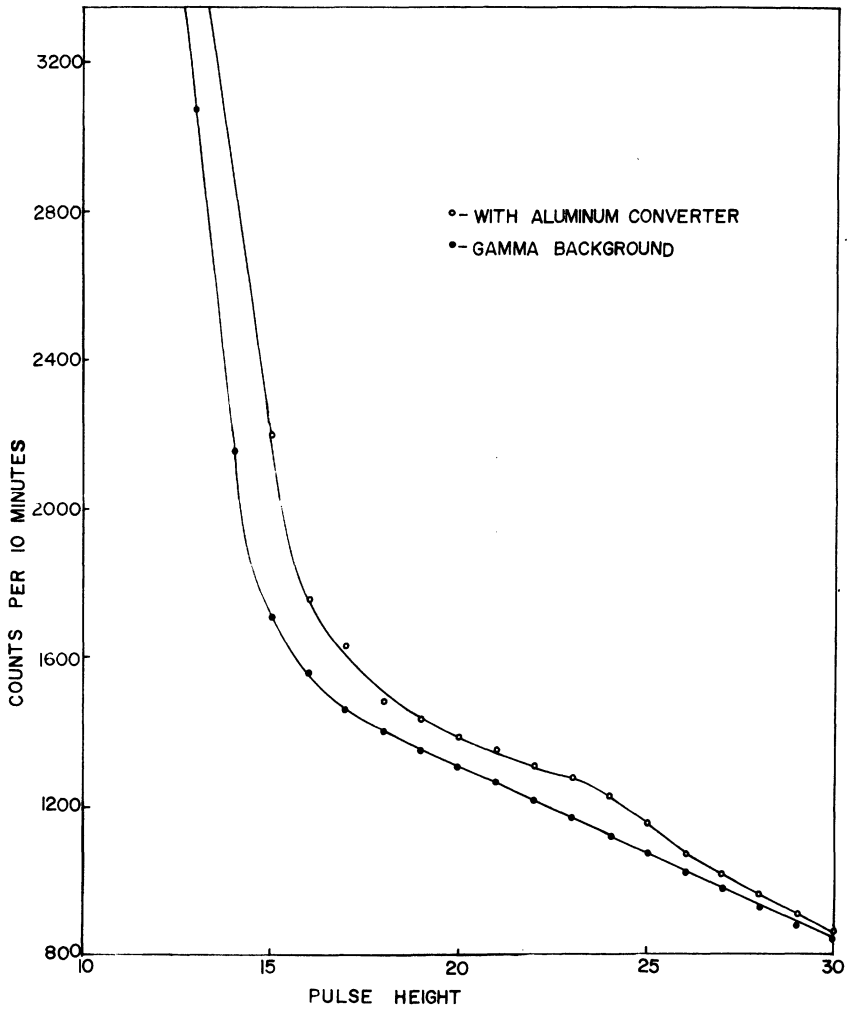

FIG. 2 Typical pulse-height spectra.

well. The scintillator was further covered with a black adhesive tape. The scintillator was carefully centered on the photon beam.

Thin converter foils of mass 9.8, 9.1, 12.0, and 8.05 mg/cm^2 of Zr, Ag, Sn, Ta, and Pb, respectively, of high purity (99.9%) were punched to the size of the well diameter. Then the converter foil under investigation was placed inside the scintillator well intercepting the entire photon beam. Plastic strips were used to insert the converter foils into the well. On the basis of the measurements of the beam profile it was confirmed that the converter foil at all the times intercepted the entire photon beam. After inserting the foil, the well top was covered with a thin black adhesive tape.

The pulses from the photomultiplier were coupled to the cathode follower which then fed these pulses to the single-channel analyzer. The experiment was performed in an air-conditioned room. The main voltage was also stabilized. The drift in the spectrometer gain was neglibible.

III. PROCEDURE

When a low-energy photon beam is incident on a converter material, electrons are ejected due to photoelectric absorption and Compton collisions. The γ background spectrum and the spectra with aluminum and other converters (Zr, Ag, Sn, Ta, and Pb) were recorded. Typical pulse-height spectra are given in Fig. 2. The γ background spectrum was subtracted from the aluminum spectrum and the resolved electron spectrum is plotted in Fig. 3. As can be seen from the figure there is a small hump which is due to the photoelectron spectrum superimposed on the Compton continuum. In the resolved electron spectrum the Compton continuum is interpolated by curve fitting (shown by dotted line). No signif-

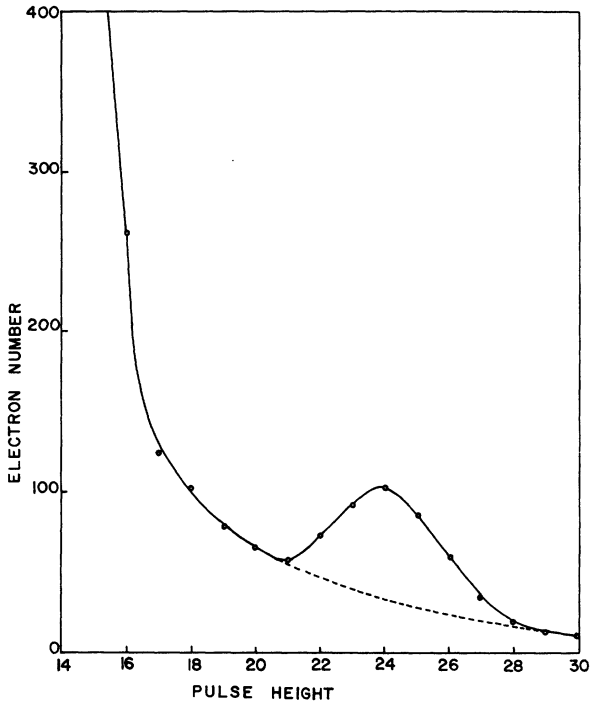

FIG. 3. Resolved electron spectrum of aluminum converter. The dotted line is the intrapolated Compton continuum.

icant error can be found in the interpolation due to the general smoothness of the continuum. This Compton continuum together with the ratio of the number of electrons in the high-Z converter material to that in aluminum was used to estimate the Compton continuum in that material. The Compton continuum so obtained was subtracted from the observed electron spectrum in the high-Z converter. The resolved photoelectron spectra were plotted; typical spectra obtained in the case of Zr and Pb are shown in Fig. 4. For monoenergetic electrons, the pulse amplitude spectrum in the scintillators is mainly a Gaussian,[8] except at the lower-amplitude side, where it is distorted due to the backscattering of electrons on the surface of the scintillator. By using the well-type scintillator this has been minimized to a large extent. Because of the poor resolution of the spectrometer the contribution from the different shells (K, L, M, ..., etc.) are not completely resolved. The main peak in the spectrum is attributed to the K-shell electrons and using the left portion of the peaks Gaussians were fit. The areas under these Gaussians would then give the respective number of K-shell photoelectrons. The linearity of the spectrometer was also checked by plotting the K-shell photopeak energy against the corresponding pulse height (Fig. 5). The estimated number of K-shell photoelectrons was then corrected for self-absorption[9] in respective converter foils. This corrected number (N_k) was used in the calculations of the K-shell photoelectric cross sections.

The converter foils were weighed in an electrical balance and the number of atoms (N) in the foil was estimated using the relation $N=mL/A$, where m and A are the mass and the atomic

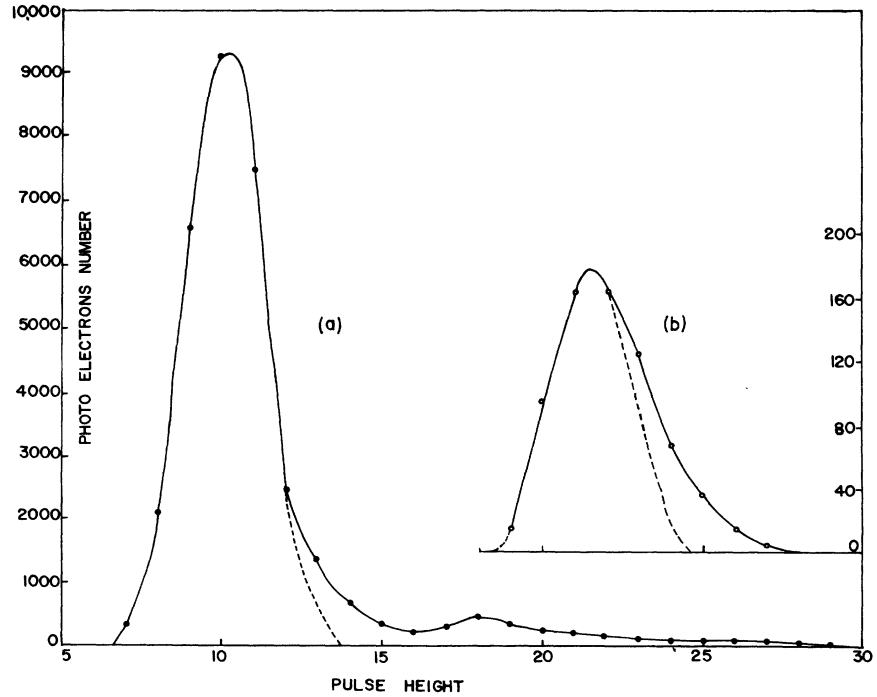

FIG. 4. Resolved photoelectron spectra (the area under the Gaussian fitted to each spectrum gives the number of respective K-shell photoelectrons); (a) in lead; (b) in zirconium.

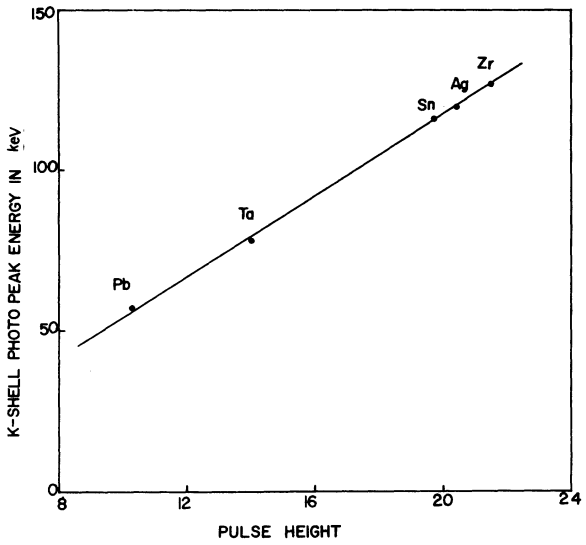

FIG. 5. Plot of K-shell photopeak energy against their corresponding pulse heights.

weight of the converter material, respectively, and L is the Avagadro number.

To determine the number of photons that are incident on the converter foil, a scintillation spectrometer was assembled with a 38-mm-diam and 38-mm-thick NaI (Tl) crystal which was coupled to an RCA 6292 photomultiplier. The spectrum of Ce^{141} was recorded in a good geometry setup.[10] The photoelectric events due to 145-keV γ rays were registered in the scaler. This number was corrected for photopeak efficiency and geometric efficiency by determining the peak-to-total ratio experimentally. The intrinsic efficiency for the crystal employed was taken from the theoretically computed values of Wolicki *et al.*[11] for point-source geometry. This was further corrected for the geometry of the setup. The data were also corrected for absorption in the aluminum shield of the NaI(Tl) crystal. Using this value, the number of photons (S) incident on a unit area of the converter foil was calculated.

TABLE I. K-shell photoelectric cross sections in b/atom.

Element	Present	Schmickley and Pratt
Zr	32 ± 2	34.6
Ag	68 ± 4	69.0
Sn	83 ± 5	86.0
Ta	348 ± 21	347.0
Pb	537 ± 32	549.0

IV. RESULTS

The K-shell photoelectric cross sections have been calculated by using the relation

$$\sigma_k = N_k / NS$$

and tabulated in Table I.

The error involved in the present experimental cross sections depends mainly on the accuracy in determining the number of K-shell photoelectrons, the γ-ray flux, and the number of atoms in the converter foil. The error in the K-shell photoelectron number is found to be less than 6%. This error comes mainly from the subtraction procedure and the statistical uncertainties in the estimated Compton electrons (5%) and the total number of electrons beneath the photoelectron peak (< 3%). The error in the estimation of photon flux is less than 1%. Since the mass of the converter foil is determined using the electrical balance, the error in the estimation of the number of atoms in the foil is very small (< 0.2%) and is therefore neglected. Hence the effective error involved in the measured cross sections is about 6%.

The measured cross sections are compared with the interpolated values of Schmickley and Pratt[7] and there is good agreement between the two.

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