Photon cross sections in Cu, Pt, and Au at 81 keV

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Total photon cross sections in Cu, Pt, and Au are measured employing the doublet 79.623- and 80.999-keV γ's of ^{133}Ba. A dilution of the cross section by about 12% is observed at the average energy of the doublet in Au due to K-edge falling in between these two energies. Scofield's theoretical value in this case is seen to be underestimated by about 75% due to the use of different K-edge energies in Au. However, an alternative but customarily followed procedure is to ignore the lower K-edge data of Scofield and extrapolate using upper-edge data which yield a value agreeing satisfactorily with the experimental value at 80.905 keV.

It is a common practice to measure photon cross sections at the average energy of closely lying lines when it is not possible to resolve them by a detector. Many such measurements, particularly at low photon energies, are reported employing proportional counters or thin NaI(Tl) crystal detectors. A typical situation arises in the case of Au while measurements are made employing the doublet of energies 79.623 and 80.999 keV of a ^{133}Ba source. The K edge of Au is experimentally well established and is 80.725 keV.[1] The careful experimental work of Beckman *et al.*[2] yielded a value of 80.7205±0.005 keV which is in excellent agreement with the former value. The K edge obviously falls between the two lines in the doublet. Though the intensity[3] of 79.623 keV (37.7) is small compared to 80.999 keV (512), it will be interesting to study the effect of mixing these two intensities on the photon cross section at 80.905 keV which is the intensity-weighted average of energies. For a comparison, cross sections are also measured in Pt and Cu for which the K edges are away from the doublet energies. These results are reported with a discussion in the light of theoretical photon cross sections.[4–7]

A high-resolution Si(Li) detector capable of resolving the doublet energies 79.623 and 80.999 keV was used. A description of the geometrical set-up and the method of measuring total cross sections are reported in earlier publications.[8–10] It may be noted that Kane *et al.*,[10] who used solid-state detectors in their work, observed no systematic

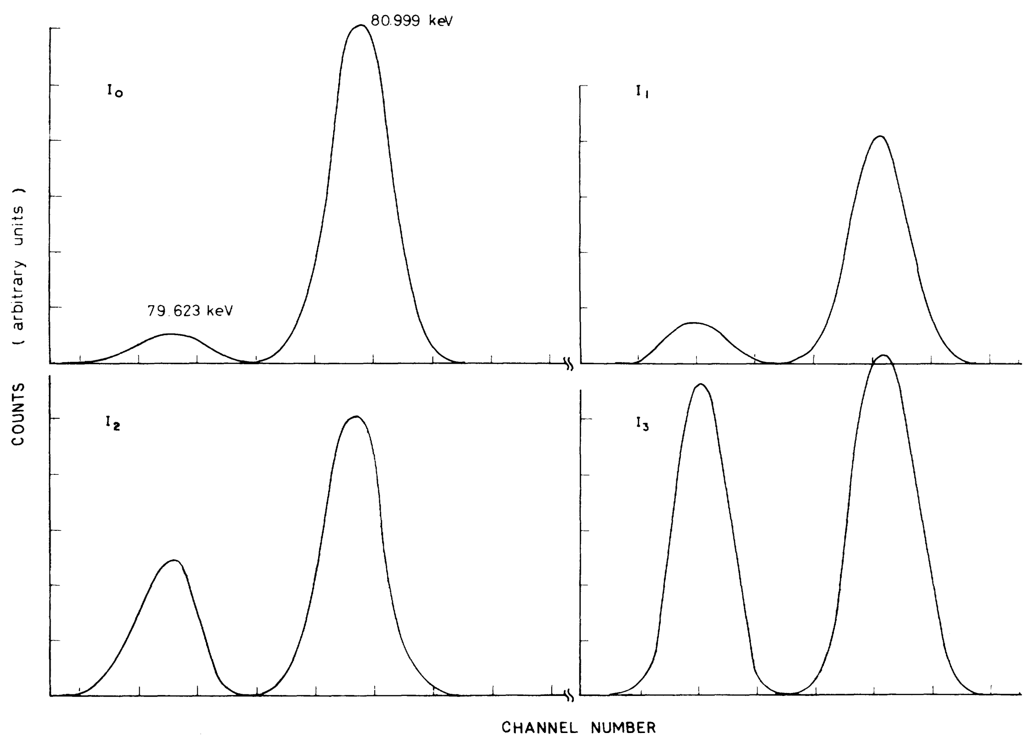

FIG. 1. Background subtracted. Photon spectra of Au (I_0: I_1,I_2,I_3). I_0: without Au foil. I_1,I_2,I_3: Transmission spectra with Au foils of different thicknesses.

variation of cross section with thickness or with μt of absorber material. The cross sections in Au, Pt, and Cu at 80.999 keV are evaluated in the usual way and at the average energy 80.905 keV they are obtained by adding the intensities of the individual lines of the doublet. Typical spectra of Au are shown in Fig. 1.

In Table I are shown the measured photon cross sections in Au, Pt, and Cu at 80.999 keV and at the average energy 80.905 keV along with the theoretical values of Storm and Israel[4] and those obtained by adding the coherent and incoherent scattering cross sections of Hubell *et al.*[5,6] to the photoelectric cross sections of Scofield.[7] In this connection it may be noted that Storm and Israel[4] and Scofield[7] adopt different points of view in naming the K edge energy in Au. As normally understood the K edge is only one single energy and is 80.725 keV in Au as stated earlier which is also the value adopted by Storm and Israel;[4] however, Scofield[7] assigns an upper and a lower limit to the K edge which are 81.51 and 80.923 keV, respectively. Therefore, in order to evaluate the cross section at 80.999 keV, the data above 81.57 keV are extrapolated down to 80.999 keV while the cross section at 80.905 keV is obtained from the data below 80.923 keV by interpolation. Since 80.923 keV happens to be the lower-edge limit of Scofield,[7] which is higher than the present average energy 80.905 keV, our method of obtaining cross section at 80.905 keV by interpolation using the lower energy data is justified. However, an alternative method of determining the cross section at 80.905 is also followed. Since the experimentally well-established K edge of Au is 80.725 keV and is lower than the lower edge of Scofield, the data of Scofield below 81.57 keV is extrapolated to 80.905 keV ignoring the lower edge 80.923 keV of Scofield. This latter method yields a cross section agreeing satisfactorily with the experimental result as seen from Table I. However, whether one can ignore the lower-edge data makes this procedure questionable. It can be seen from Table I that agreement between theory and experiment is more or less satisfactory in all cases but Au at the average energy of 80.905 keV only. At this energy, of the two theoretical cross sections the one of Storm and Israel[4] is larger than that of Scofield[7] and Hubbell *et al.*[5,6] which is far smaller.

It can be seen from Fig. 1 that the absorption of 79.623 keV intensity is smaller than that of the 80.999-keV intensity because of the jump in the cross section at the K edge in Au at 80.725 keV. Therefore, mixing the intensities of 79.623- and 80.999-keV lines also resulted in a dependence of the cross section on transmission beyond the experimental errors. The possible contribution of $K\beta x$ rays produced in Au by the primary photons to the general decrease of the cross section is also estimated and found to be small. It may be noted from Fig. 2 that the cross section in Au at 80.905 keV steadily decreases with increasing μt corresponding to transmission range 30% to 5% and therefore an average value is adopted and is given in Table I. This value can be seen to be about 12% smaller than the corresponding theoretical value of Storm and Israel[4] which can be seen from Table I. This large deviation only at 80.905 keV in Au can possibly be attributed to (a) the dilution of the transmitted intensity by that of 79.623 keV and (b) effect of finite-level width of Au K edge. Table I also shows that the theoretical value of Scofield[7]

TABLE I. Photon cross sections in barns per atoms. Expt.: present value; SI: Storm and Israel (Ref. 4); Sc-H: Scofield photoelectric effect (Ref. 7) and Hubbell *et al.* scattering (Refs. 5 and 6).

Element		79.623 keV	80.999 keV	80.905 keV
Cu	Expt.	80±2.5	77.3±1.0	77.4±1.0
	SI	80.870	77.6	77.7
	Sc-H	81.4	78.2	78.4
Pt	Expt.	2900±90	2740±55	2782±54
	SI	2885	2761	2769
	Sc-H	2875	2738	2749
Au	Expt.	720±21	2870±60	2530±60
	SI	713.4	2836	2844
	Sc-H	723	2888	695 2895[a]

[a]Sc-H, value based on Scofield's value obtained by extrapolating his upper-edge data ignoring lower-edge data.

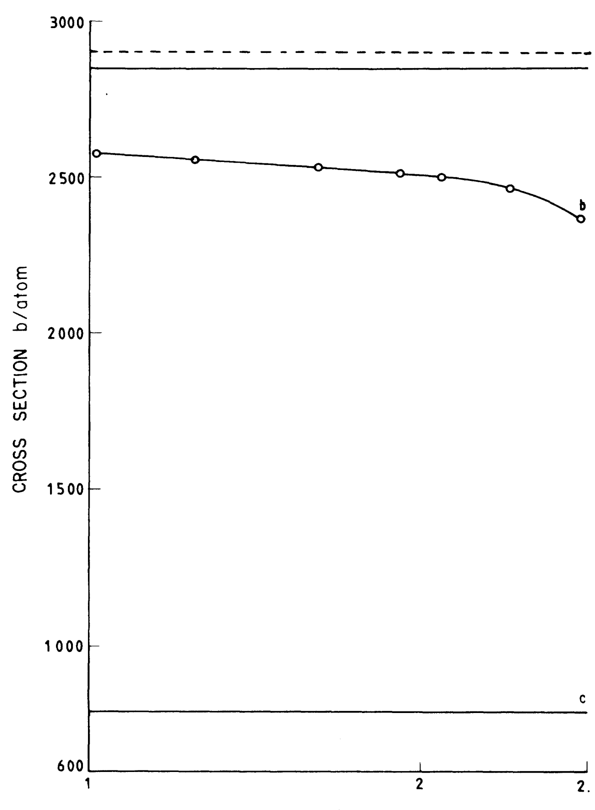

FIG. 2. Plot of cross section vs μt for Au for the 80.905-keV intensity-averaged energy. (a) Theoretical value of Storm and Israel. (b) Present experimental value. (c) Theoretical value of Scofield and Hubbell based on Scofield's values interpolated from his lower-edge data. (d) Theoretical value of Scofield and Hubbell based on Scofield's value extrapolated from his upper-edge data.

plus Hubbel *et al.*[5,6] in Au at 80.905 keV is at great variance with either the experimental value or the theoretical result of Storm and Israel.[4] It is very much smaller than either, indicating that Scofield's[7] theory highly underestimates photo-electric cross section at 80.905 keV in Au by about 75% where the contribution due to coherent and incoherent scattering is small ($\sim 5\%$). This underestimation is possibly due to the fact that 80.905 keV falls below the lower-edge limit in Scofield's[7] data while it lies above the K edge in the data of Storm and Israel[4] in Au. In the case of Pt, it is observed that the cross section at 80.905 keV remains constant within experimental errors for all μt corresponding to transmissions up to 10% and deviates only marginally from this value for 5% transmission. No such deviation is found in the case of Cu.

The conclusions of the present investigations are broadly threefold: (a) the photon cross section measurements at the average energy of two closely lying lines, especially when the K edge of the element of interest falls in between them, will not yield accurate cross section; (b) all the cross sections measured agree satisfactorily with the theoretical values of Storm and Israel; however, while comparing with Scofield's data in the case of Au, it must be said that interpolation of his lower-edge data to 80.905 keV yields a greatly underestimated cross section while extrapolating his upper-edge data yields a satisfactory value; in all the other cases there is good agreement with Scofield's data also; and (c) for elements where K edges are near the doublet energies, like Pt in the present case, it is not advisable to go beyond 10% transmission to determine photon cross sections.

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