Measurement of Ll, $L\alpha$, $L\beta$, and $L\gamma$ x-ray production cross sections in some high-Z elements by 18-, 26-, 33-, and 44-keV photons

N. Singh, Raj Mittal, Bhajan Singh, K. L. Allawadhi, and B. S. Sood
Nuclear Science Laboratories, Department of Physics, Punjabi University, Patiala 147002, Punjab, India
(Received 6 February 1986)

The cross sections for the production of Ll, $L\alpha$, $L\beta$, and $L\gamma$ x rays in the elements Ta, W, Au, Hg, Tl, Pb, Bi, Th, and U by photons of energies 17.781, 25.770, 32.890, and 43.949 keV have been measured, using a standard double-reflection experimental setup. The measured values have been interpreted in terms of the photoionization cross sections, fluorescence yields, Coster-Kronig transition probabilities, and radiative decay rates. A fairly good agreement is found between the experiment and calculations.

INTRODUCTION

Our earlier measurements[1] of Ll, $L\alpha$, $L\beta$, and $L\gamma$ x-ray production cross sections in high-Z elements at 59.57 keV have been extended to photon energies of 17.781, 25.770, 32.890, and 43.949 keV. These measurements are made with a view to examine the details of L-shell photoexcitation and deexcitation processes and provide some useful data needed in the investigation of various phenomena and processes involving L x-ray emission. Reliable values of these cross sections are also needed for the estimation of trace and other elements in various types of samples, using photon-induced x-ray fluorescent technique.

The direct measurements of the physical parameters (e.g., L-subshell ionization cross sections, fluorescence yields, Coster-Kronig transition probabilities, and radiative decay rates) involved in the excitation and deexcitation processes present many problems. It is, therefore, difficult to test directly the different theoretical calculations of these parameters that are available in literature. However, these calculations may be tested indirectly by comparison of the results of the present measurements of x-ray production cross sections with those calculated using the theoretical values of the parameters. Omitting the details which have been published earlier,[1] the salient features of the method of measurement and analysis of results are summarized in this paper.

EXPERIMENTAL ARRANGEMENT, METHOD OF MEASUREMENTS, AND RESULTS

The external-conversion K x rays of weighted mean energies 17.781, 25.770, 32.890, and 43.949 keV and characteristic of elements Mo, Sn, Ba, and Gd, respectively, are used to excite, in turn, L x rays in elements of Ta, W, Au, Hg, Tl, Pb, Bi, Th, and U. The measurements are made using a double-reflection geometrical setup.[2] The experimental arrangement is slightly different from the one used earlier[1,2] and is shown in Fig. 1. In the present measurements the x-ray detector is placed along perpendicular to the plane containing radioactive source R, primary target P, and secondary target S, instead of keeping it in this plane. The reasons for the superiority of the present over the previous arrangement[2] in reducing background effects in the spectrum of radiation emerging from the secondary target has been discussed earlier.[3] Briefly, the primary scattering at 90° is almost completely plane polarized and does not scatter again at 90° from the secondary target into its own plane of polarization. The present arrangement, thus, reduces the scattering background considerably.

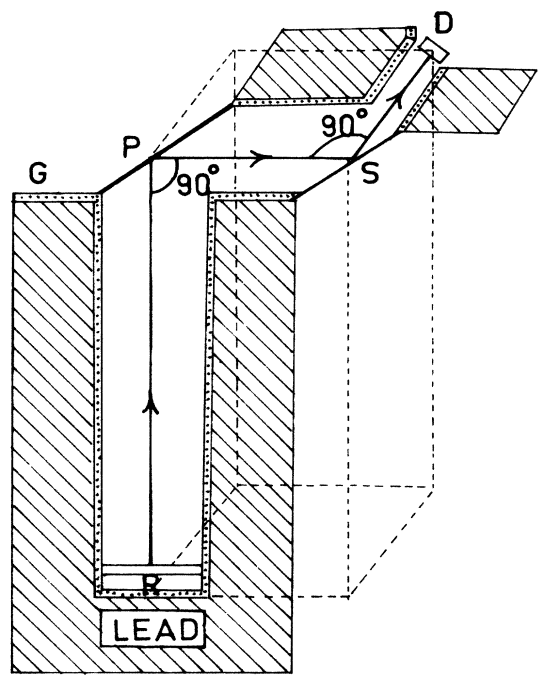

FIG. 1. Experimental setup for measurement of x-ray production cross section: R, ^{241}Am source; P, primary target; S, secondary target; D, detector; G, graded absorber of Fe and Al. D is placed in a plane perpendicular to the RPS plane.

59.57-keV gamma rays from ~ 1 Ci ^{241}Am source are collimated, in turn, on primary targets of Mo, Sn, Ba, and Gd and the radiation emitted from the primary targets are collimated, in turn, on the secondary targets of Ta, W, Au, Hg, Tl, Pb, Bi, Th, and U. The L x rays emitted from the secondary targets are counted under the Ll, $L\alpha$, $L\beta$, and $L\gamma$ peaks by a calibrated x-ray spectrometer coupled to an ND600 multichannel analyzer system. The resolution of the Si(Li) x-ray spectrometer is ~ 300 eV at 5.9 keV. A typical L x-ray spectrum is shown in Fig. 2. The details of the method of calibration are discussed earlier.[1] The choice of the primary and secondary target element is such that the primary characteristic K x rays are unable to ionize the K but are able to ionize L and higher shell electrons of the secondary target elements. Since vacancies are not created in K shell, no transfer of vacancies occurs from K to L shell. All the initial vacancies in the L shells of the secondary target element are produced by the photoionization of L electrons by the primary K x rays and the coherent and incoherent scattering of 59.57-keV gamma rays from the primary target. The relative contribution of the two components (K x rays and scattering) to the total L x-ray production is governed by the following factors: (1) relative intensities of K x rays and scattering radiation falling on the secondary target; (2) relative L-shell photoionization cross sections at the energies of K x rays and scattered radiation.

It is evident that the relative intensities of K x rays and scattered radiation falling on the secondary target depends upon the K-shell photoionization and scattering cross sections at 59.57 keV and the effective material from which the two processes take place. In order to minimize the contribution due to scattering it is desirable to use self-supporting primary targets and avoid the use of any shielding material behind the primary target, so that it does not act as unwanted scattering material. In the present experiment, the contribution due to scattering is taken into account by taking a background spectrum with an equivalent Al primary target as explained earlier.[2] The experimental and theoretical cross sections for production of Ll, $L\alpha$, $L\beta$, and $L\gamma$ x rays are determined and/or evaluated from the relation explained in the earlier communication.[1]

Recently, K- and L-shell intensity ratios have also been measured by some workers[4,5] using a geometrical setup different from the present one, popularly known as the annular-ring geometry, and very thin targets (~ 100–500 μgm/cm^2). The annular-ring geometry may provide somewhat larger source-primary target solid angles but the other benefits of the present geometrical setup have to be sacrificed. In the annular-ring geometry, neither can the x-ray detector be kept perpendicular to the plane of source, primary and secondary targets, nor can the self-supporting primary targets without any shielding material behind it be used. The use of thin secondary targets also does not seem to show much promise. For example, in the experiment of Garg *et al.*[5] for a typical case of Pb target of 300 μgm/cm^2, more than 99.5% of photons of energy 40 keV will be transmitted without any interaction, thereby decreasing the signal-to-background ratio considerably. The percentage uniformity in thickness of these targets is also low. Both these factors will add to uncer-

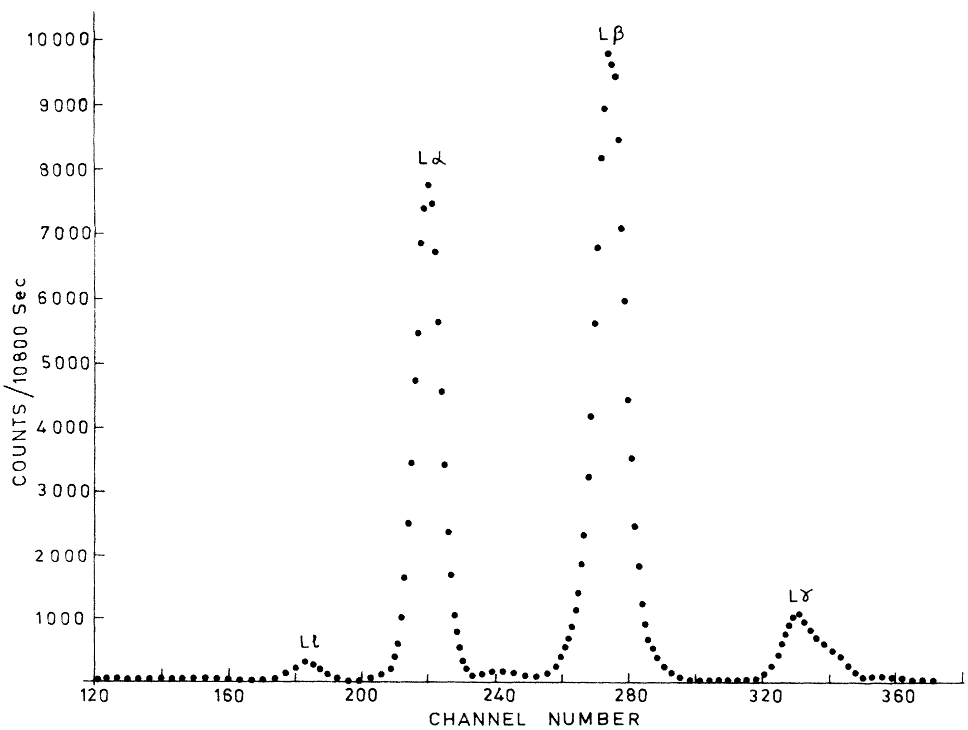

FIG. 2. Secondary spectra (Pb L x rays) recorded with Si(Li) low-energy photon spectrometer; Ba primary and Pb secondary (background with Al primary and Pb secondary is subtracted out).

tainties in the final results. A comparison of L x-ray spectra taken in the two geometries brings out that there exists a sizable continuum under the L x-ray peaks in the spectrum reported by Garg *et al.*[5] There is, thus, need for a detailed analysis of the background effects for the annular-ring geometry as has been reported earlier[6] for our geometry.

The measured and calculated values of the various groups of L x-ray lines in various elements at different photon energies are compared in Fig. 3. The errors shown in the present measurements are $\sim$6–8 % and are due to counting statistics and uncertainties involved in the deter-

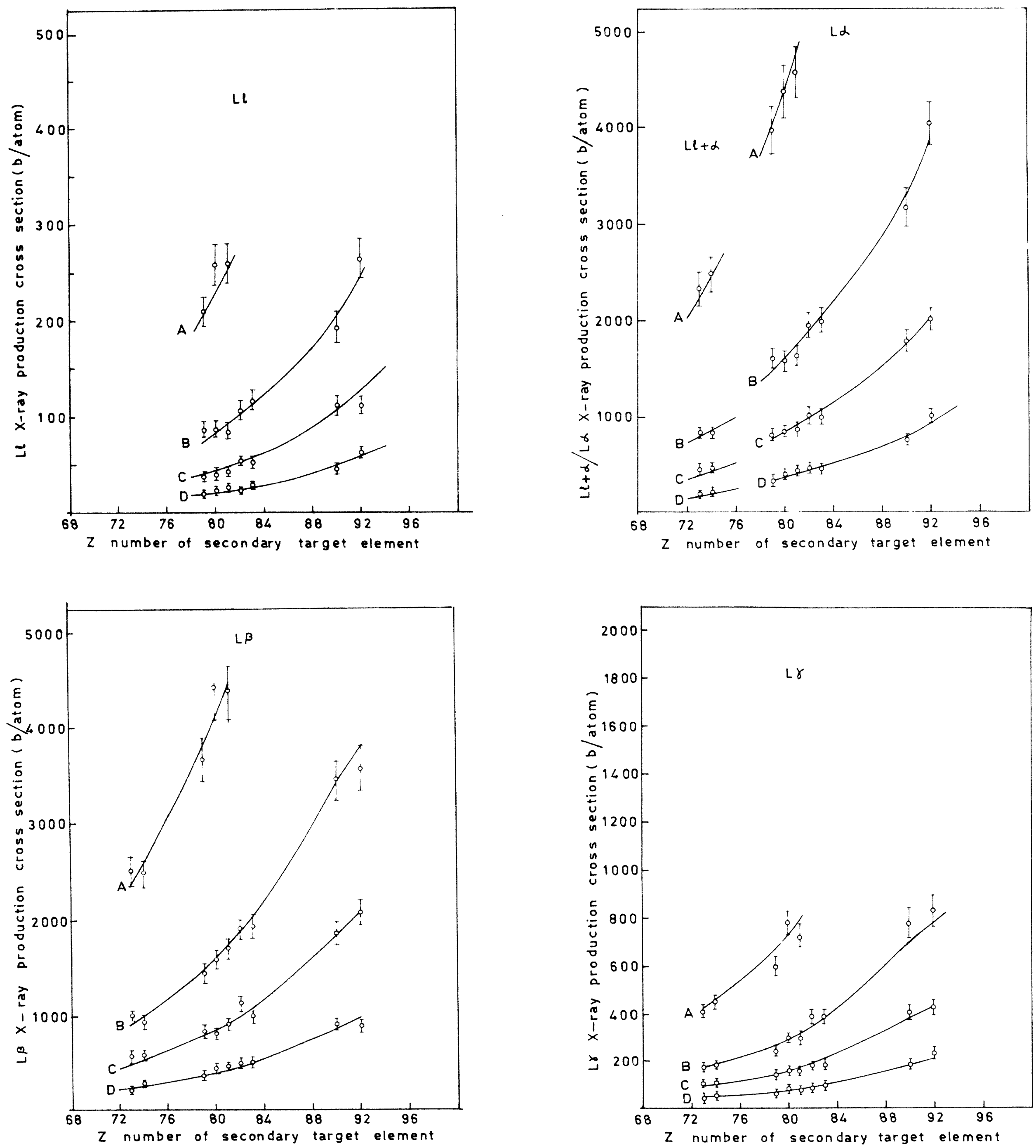

FIG. 3. Experimental values of Ll, $L\alpha$, $L\beta$, and $L\gamma$ x-ray production cross sections are compared with calculated (Ref. 1) values. The measurements are at A, 17.781 keV; B, 25.770 keV; C, 32.890 keV; and D, 43.949 keV. Dots indicate experimental data and the solid curves indicate the calculated values (Ref. 1).

mination of other parameters needed for the measurement of the cross sections.[1] A fairly good agreement is found between experimental and calculated values, especially when it is kept in mind that the uncertainties[7] in the values of Coster-Kronig transition probabilities and the subshell fluorescence yield used in the calculation of cross sections vary from 5 to 20%.

[1] K. Shatendra, K. L. Allawadhi, and B. S. Sood, Phys. Rev. A **31**, 2918 (1985).

[2] B. S. Sood, K. L. Allawadhi, and S. K. Arora, Nucl. Instrum. Meth. **193**, 391 (1982).

[3] K. L. Allawadhi, R. Mittal, and B. S. Sood, J. Inst. Soc. Ind. **15**, 191 (1985).

[4] Chander Bhan, S. N. Chaturvedi, and N. Nath, X-Ray Spectrom. **10**, 128 (1981).

[5] M. L. Garg, Jasbir Singh, H. R. Verma, Nirmal Singh, P. C. Mangal, and P. N. Trehan, J. Phys. B **17**, 577 (1984).

[6] K. Shatendra, K. L. Allawadhi, and B. S. Sood, Pramana **22**, 79 (1984).

[7] M. O. Krause, J. Phys. Chem. Ref. Data **8**, 307 (1979).