Total γ-ray cross-section measurements with accuracy close to 1% with a high-resolution detector

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Extensive study is made to obtain the total γ-ray cross sections with an accuracy close to 1% in Pb at 276.4, 295.96, 302.86, 316.508, 356.04, 383.86, 468.07, 484.58, 588.584, 604.414, and 612.465 keV. The basic idea behind these measurements is that the data available on total γ-ray cross sections are rather meager, especially at higher energies with γ-ray sources showing highly complex energy distribution. For measuring the cross sections, a transmission experiment is conducted using a good geometry setup and a high-resolution hyperpure germanium detector. In a transmission experiment, there is a chance of underestimation of these cross sections due to small-angle scattering. Photopeaks evaluated must be free from scattering contributions as well as background. Measures are taken to account correctly for the included small-angle scattering. The measured values are compared with the available theoretical, semiexperimental and other experimental data and are in good agreement. The effect of collimation and good geometrical arrangements on the cross section is discussed.

I. INTRODUCTION

Studies on the interaction of γ rays with matter are useful from both basic and applied research points of view. Usually a transmission experiment is employed in obtaining these cross sections.[1,2] With the advent of solid-state detectors whose resolution is rather high, it has become possible to measure these cross sections very accurately. Also the data available are rather meager especially at higher energies using γ-ray sources showing complex energy distribution. Hence it is of interest to measure the total γ-ray cross sections at the below-mentioned energies using a high-resolution hyperpure germanium (HPGe) detector and a good geometry setup for comparison with the available theoretical,[3] semiexperimental,[4] and other experimental data.[5,6] More accurate theoretical total cross sections can be obtained for comparison by adding the photoelectric cross sections of Scofield[7] with stated accuracies in this energy region ranging from 0.3% to 1.3% and the recently reported nonrelativistic cross sections of coherent and incoherent scattering by Hubbell *et al.*[8] More recently Hubbell *et al.*[9] reported relativistic coherent scattering cross sections. However, the influence of these new values on the total cross section is negligibly small. In the present experiment extensive investigations are carried out on total γ-ray cross section measurements in Pb at the energies 276.4, 295.96, 302.86, 316.508, 356.04, 383.86, 468.07, 484.58, 588.584, 604.414, and 612.465 keV.

II. EXPERIMENTAL DETAILS

For accurate measurement of these cross sections, a good or narrow-beam geometry setup is used. A variety of good geometry setups have been reported by many investigators.[1,10–12] In the present experiment a similar geometrical setup used by Radhakrishna Murty *et al.*[1] was developed. As the detector used is of a horizontal mounting type a horizontal-type good-geometry setup was used as shown in Fig. 1.

The detecting system consists of an ORTEC hyperpure germanium detector with associated electronics and an ND 512 channel analyzer. The detector is of horizontal configuration with an effective volume of 80 cm^3. Preliminary investigations were carried out with the detector systematically and the detector was operated at the best conditions (2500 V). The resolution of the detector is 2 keV at 1330 keV. Necessary arrangements were made to maintain the stability in the operating temperature as well as in the line voltage.

The procedure involved in these measurements was to record the direct and transmitted spectra without and with absorber foils, respectively, at the target slit. The data were obtained with four absorber thicknesses for the given energy in the transmission range from 5–20%. The time of collection was so adjusted that the statistical error in the direct and transmitted intensities was less than 0.2% and 0.7%, respectively.

Accurate measurement of these cross sections requires that the photopeak areas evaluated must be free from interfering radiations as well as background. This can be accomplished by the Gaussian fitting of a few points on

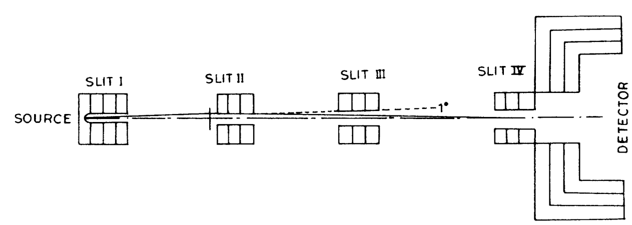

FIG. 1. Scattering in a good-geometry setup.

either side of the full energy peak which are free from other contributions. The full energy peak areas are therefore determined using a computer program of Rester.[13] This program consists of two parts. The first part fits the general background under the photopeaks to a second or third degree polynomial by the method of least squares. The data points are fitted to a Gaussian in the second part of the program after subtracting the polynomial fitted background under each data point. Any possible interference in the tailing part of the full energy peaks can be easily corrected by conveniently selecting the peak points which are free from other contributions. This program gives the area of the full energy peak along with the error and χ-square factor.

After getting the areas, corrections were applied for small-angle scattering of the incident γ rays in the absorber into the detector defined by the maximum angle θ_{max}, as shown in Fig. 1, by the following expression:[12]

$$I_R = I(e^{-\sigma_s(N/A)x}) , \quad (1)$$

where I_R is the transmitted intensity after correction, I is the observed transmitted intensity, σ_s is the scattering atomic cross section included in the maximum angle of scattering θ_{max} (coherent or incoherent as the case may be), x is the thickness of the absorber in gm/cm^2, N is the Avogadro number, and A is the atomic weight of the absorber.

σ_s is calculated using θ_{max} (in the present case 1°) and theoretical differential cross sections of the coherent and incoherent scattering reported by Hubbell *et al.*[8] In the present investigations the effect due to incoherent scattering is negligible and the effect due to coherent scattering is less than 1%. After applying the correction for the transmitted intensity, the atomic cross section μ_a can be obtained by the expression

$$\mu_a = \left[\frac{\ln\left[\frac{I_0}{I}\right]}{x} \right] \Big/ (N/A) , \quad (2)$$

where I_0 is the intensity without absorbers, I is the corrected transmitted intensity, x is the absorber thickness in gm/cm^2, N is the Avogadro number, and A is the atomic weight of the absorbers.

Since the experiment is carried out with different absorber thicknesses (in the present case four absorbers), the cross section can be calculated by the method of least squares. The standard deviation is found to be of the order of 0.7%.

Radioactive ^{133}Ba and ^{192}Ir sources in liquid form with high specific activity were obtained from the Bhabha Atomic Research Centre, Bombay, India. Very pure foils (99.99%) obtained from Chempure (Private) Limited, Calcutta, India, were used.

III. ERROR ANALYSIS

The overall error in the measured cross sections has contributions from the following factors: (a) statistical error (0.7%), (b) error in the correction for the scattering corrections, (c) error in the measurement of the thickness of the absorbers, (d) error due to impurities in the absorbers, and (e) error in the background fittings. Error due to (b) is very small since the correction itself is less than 1%. Error due to (c) is very small as all weights are measured accurately on an electrical balance. Error due to (d) is negligible as the absorbers used are 99.99% pure. Error due to (e) is also very small since a high-resolution detector is used.

Also the effect due to multiple scattering is almost negligible because of our small θ_{max} and the energy-selecting device used for detection purposes. The effects due to secondary interference events such as fluorescence radiation originating in the absorber are also negligible because of the small θ_{max}. The effect due to bremsstrahlung radiation produced in the absorber is also negligibly small. Also, this effect is negligible because of its continuous nature which can be eliminated as a continuous background. However, taking all the above factors into account, the overall error in the measured cross sections is found to be of the order of 1%.

IV. RESULTS AND DISCUSSION

A typical γ-ray transmitted spectrum of ^{133}Ba in Pb is shown in Fig. 2. In Table I the experimentally measured values are compared with the available theoretical, semiexperimental, and other experimental data obtained with solid-state detectors. Interpolated values from the available data are used at the energies of interest. It can be seen that the present values are in stationary agreement with the semiexperimental data of Veigele.[4] However, the reported error in the semiexperimental data is more than 2%. It is seen that the present data are in agreement with the theoretical data of Storm and Israel[3] and the combined data of Scofield[7] and Hubbell *et al.*[8] within the range of experimental errors. However, a close observation shows that the present data are in a better agreement with combined data of Scofield and Hubbell *et al.* than that of Storm and Israel. The measured values are in satisfactory agreement with the experimental values of Henry and Kennett[5] within the range of error. The experimental data of Christmas[6] are not in agreement with the present data at most of the energies. Christmas measured these cross sections without collimation. Thus the effect

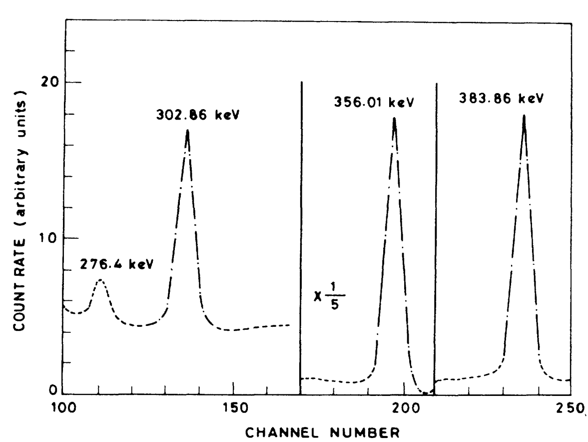

FIG. 2. Typical γ-ray transmitted spectrum of ^{133}Ba in Pb.

TABLE I. Total γ-ray cross sections (barns/atom) comparison with theoretical, other experimental, and semiexperimental values. Expt. denotes experimental values; V, Veigele (error is 2% or more, Ref. 4); HK, Henry and Kennett (error $\sim 1\%$, Ref. 5); CH, Christmas (error $\sim 1\%$, Ref. 6); SI, Storm and Israel, Ref. 3; SH, Scofield (Ref. 7) and Hubbell *et al.* (Ref. 8).

Energy (keV)	Element: Pb	Energy (keV)	Element: Pb
276.4		356.04	
Expt.	163±1.6	Expt.	97.5±1.0
V	162.5±3.2	V	96.7±2
HK	163.5±1.6	HK	97.3±1
CH	147.65±1.5	CH 8	96.5±1
SI	165	SI	98.6
SH	163.4	SH	98.2
295.96		383.86	
Expt.	140.3±1.4	Expt.	84.1±0.9
V	139.2±2.8	V	83.6±1.6
HK	141.54±1.4	HK	85.9±0.9
CH	131.60±1.3	CH	85.05±0.9
SI	141.0	SI	85.0
SH	141.6	SH	85.4
302.86		468.07	
Expt.	132.5±1.3	Expt.	60.2±0.6
V	132.5±2.6	V	59.2±1.2
HK	134.8±1.3	HK	61.86±0.6
CH	126.6 ±1.3	CH	60.95±0.6
SI	134.5	SI	60.9
SH	135	SH	61.0
316.508		484.58	
Expt.	122±1.2	Expt.	57.3±0.6
V	121.6±2.4	V	55.9±1.2
HK	122.82±1.2	HK	58.4±0.6
CH	117.60±1.2	CH	57.5±0.6
SI	123.5	SI	57.6
SH	123.6	SH	57.8
588.584		612.465	
Expt.	43.2±0.4	Expt.	40.7±0.4
V	41.85±0.8	V	39.7±0.8
HK	44.56±0.4	HK	42.32±0.4
CH	41.48±0.4	CH	38.94±0.4
SI	43.6	SI	41.4
SH	43.7	SH	41.5
604.414			
Expt.	41.8±0.4		
V	40.34±0.8		
HK	43.05±0.4		
CH	39.67±0.4		
SI	42.0		
SH	42.2		

of collimation and good-geometrical arrangement is seen for these total cross-section measurements even with a high-resolution detecting system. The obtained data are showing the expected variation with energy according to the theoretical trends. It can be seen from the obtained data that a high-resolution detector is of immense use in measuring these cross sections with highly complex radioactive sources.

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[1]V. Radhakrishna Murty, K. Parthasaradhi, and V. Lakshminarayana, Nuovo Cimento A **39**, 125 (1977).
[2]R. S. Prakhya, V. Lakshminarayana, K. Parthasaradhi, K. L. Narasimham, and K. V. Ramaniah, Phys. Rev. A **33**(3) (1986).
[3]E. Storm and H. I. Israel, Nucl. Data **7**, 565 (1970).
[4]Wm. J. Veigele, At. Data **5**, 51 (1973).
[5]L. C. Henry and T. J. Kennett, Can. J. Phys. **49**, 1167 (1971).
[6]P. Christmas, Int. J. Appl. Radiat. Isot. **25**, 25 (1974).
[7]J. H. Scofield, UCRL Report No. 51326 (1973) (unpublished).
[8]J. H. Hubbell, Wm. J. Veigele, E. A. Briggs, R. J. Brown, D. T. Cromer, and R. J. Howerton, J. Phys. Chem. Ref. Data **4**, 471 (1975).
[9]J. H. Hubbell and I. Overbo, J. Phys. Chem. Ref. Data **8**, 69 (1979).
[10]S. A. Colgate, Phys. Rev. **87**, 572 (1952).
[11]V. Lakshminarayana and S. Jnanananda, Proc. Phys. Soc. London **77**, 593 (1961).
[12]K. Premchand, V. Lakshminarayana, D. K. S. Reddy, J. Rama Rao, and V. Radhakrishna Murty, J. Phys. B **9**, 177 (1976).
[13]A. C. Rester (private communication).