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Studies on External Bremsstrahlung in thick target compounds

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Abstract

Most of external Bremsstrahlung (EB) works of beta have been carried out using only metal as a thick target but using compound as a thick target is lacking. Present study is made to (i) follow the interpolation technique to extend the existing theory from elements to compounds (ii) focus on various compounds which can be used as targets for incident beta particles to produce EB spectrum (iii) compare experimental results with the theory suitably extended to compound. Experiment has been carried out in a good geometry set up. In the present study, beta source such as ^{204}Tl (0.766 MeV) and thick target compounds, $PbCl_2$ and CdO have been used. After carrying out the unfolded procedure, measured spectrum has been compared with the theoretical spectrum.

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Keywords: External Bremsstrahlung; Radiation; Compound; Spectrum; Beta

1. Introduction

External Bremsstrahlung (EB) is a continuous electromagnetic radiation emitted when an electron or a beta particle is deflected in the coulomb field of the nucleus. Sommerfeld [1] developed a theory for EB produced by a non-relativistic electron in the coulomb field of the nucleus of a thin target. Bathe-Heitler[2], Sauter[3] and Racah[4] obtained an analytical expressions for the relativistic case by neglecting coulomb effects of the nucleus. An accurate theory has been developed by Tseng–Pratt[5] using the self-consistent coulomb field wave function. Seltzer[6] extends the Tseng–Pratt theory to the field of an atomic electron. Theoretical methods for calculating thick targets have been formulated by many authors. Also many experimental studies have been made using thin targets and thick targets. From this survey, it is found that the discrepancy between theory and experiment increases with atomic number of the target, photon energy. Most of the EB works of beta have been carried out using only metal as a thick target but using compound as a thick target is lacking. Vanderwood [7] measured Bremsstrahlung intensities for a set of compound samples and found a definite discrepancy with Kramer's law. Markowicz [8] proposed a new and accurate expression for modified atomic number for a compound by taking into account the self-absorption of Bremsstrahlung and electron back scattering. Shivaramu [9] determined effective atomic number for a set of compound samples from the measured EB yields. EB imaging technique[10] is being used world wide to diagnosis of metastases of a human bone (treated as a compound) in which the given beta source is placed.

1.1. Present study

Present study is made to (i) follow interpolation technique to extend the existing theory from elements to compounds (ii) focus on various compounds which can be used as targets for incident beta particles to produce EB spectrum (iii) compare experimental results with the theory suitably extended to compound.

1.2. Interpolation technique

EB cross section of a compound ($\sigma_{Z'}$) has been estimated using the following Lagrange's interpolation

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method [11]:

$$\sigma_{Z'} = \Sigma\sigma_z \left\{ \prod_{Z' \neq Z} (Z' - Z) / \prod_{z \neq Z} (z - Z) \right\} \quad (1)$$

here z is the atomic number of the element of known EB cross section σ_z adjacent to the modified atomic number Z' of a given compound whose EB cross section $\sigma_{Z'}$ is desired and Z are atomic numbers of other neighboring elements of known EB cross sections. Z' has been estimated by the following method [8]

$$Z_{\text{mod}} = \frac{\sum_i^l \frac{W_i Z_i^2}{A_i}}{\sum_i^l \frac{W_i Z_i}{A_i}} \quad (2)$$

where l indicates the number of elements in the compound and W_i, A_i, and Z_i are the weight fraction, atomic weight and atomic number of the ith element present in the compound, respectively. The available theoretical data of σ_z [6] are used in (1).

1.3. Present experimental method

The beta source ^{204}Tl was obtained from Bhabha Atomic Research Centre, Bombay, India The measured spectrum [12] of this beta source is as shown in Fig. 1. The details of experimental arrangement are as explained elsewhere [13]. A 3.8 cm × 3.8 cm NaI(Tl) crystal detector mounted on photomultiplier was coupled to a PC based sophisticated 16 k multi channel analyzer. The crystal was housed in a hollow lead chamber. The lead chamber was lined with aluminum in side. Target compounds such as $PbCl_2$ and CdO in the fine powder form were filled in Perspex planchet of 1 cm diameter. The thickness of these compounds was so chosen to stop all the beta particles. Densities of these two compounds are given by 5.85 and 8.15 kg/m^3, respectively. Various properties such as density and melting point are checked with usual simple methods and found to be constant during experiment. The source was placed in a Perspex stand at a distance of 12.5 cm above the face of the detector. The target compound was placed between the detector and the source. The geometry was carefully adjusted to see that crystal was fully exposed to the EB emitted from the target. The MCA was calibrated using various gamma sources of energies ranging between 122 and 1330 keV before and after experiment to check the stability of the instrument.

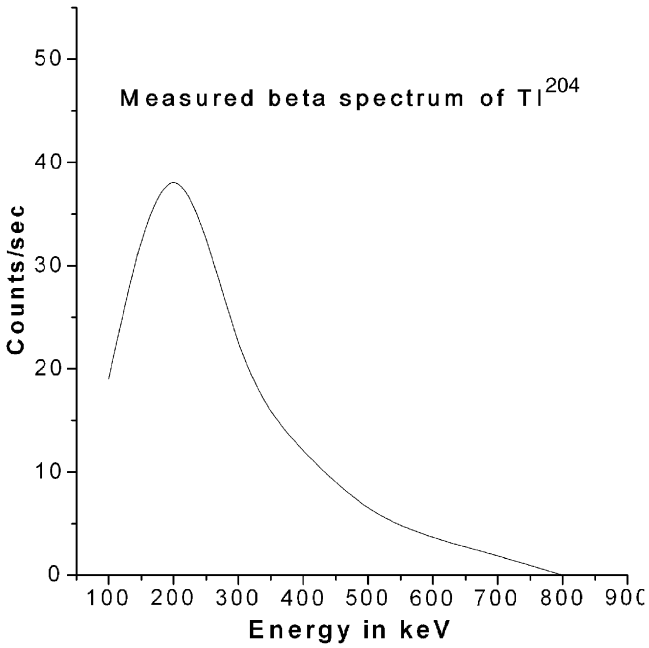

Fig. 1. measured beta spectrum of Tl^{204}.

A Perspex sheet with thickness sufficient to stop all beta particles is placed on the top of the target compound and with source in position, the spectrum EB + IB + BG was taken. Here IB and BG are internal Bremsstrahlung and background, respectively. The Perspex was then placed below the target compound and the spectrum IB + BG was recorded for the same time. The difference in the two spectra gives Raw EB spectrum. Data were accumulated each time for 12 h. From several sets of data recorded, the average of the six sets of data were used for the final analysis.

1.4. Spectrum analysis

The observed pulse height distribution is the original photon spectrum folded by the response function of the detector system. Hence observed pulse height distribution has been unfolded using the method of Lidden starfelt [14]. The observerd pulse height distribution was corrected for finite energy resolution, Compton electron contribution, Iodin k-X-ray escape peak, geometrical and gamma ray detection efficiency, etc. The spectrum is divided by beta source strength to get finally true EB spectrum which gives number of photons per moc^2 per beta, S(k).

1.5. Evaluation of theoretical EB spectrum

The theoretical spectral distribution of EB, when an incident electron of energy T is completely absorbed in thick target compound is evaluated [2] as follows:

$$n(T,k) = N \int_E^T \{\sigma(E,k)/(-\mathrm{d}E/\mathrm{d}x)\}\mathrm{d}E \quad (3)$$

here $\sigma(E, k)$ is EB cross section at photon energy k and electron energy E, N is the number of atoms per unit volume of target and E is the energy of an electron available for an interaction with the nucleus of a thick target after it undergoes a loss of certain energy. Its range is between k and T, the initial incident electron energy.

For a beta emitter with end point energy $T_{\max}$, EB theoretical spectral distribution has been evaluated

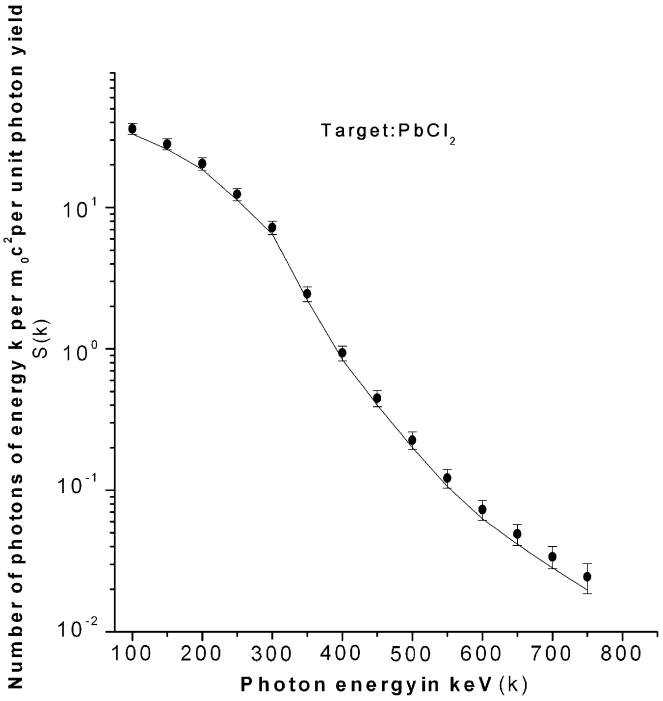

Fig. 2. Unfolded measured EB spectrum(solid circles with error bars) with theoretical spectrum(continues line) of ^{204}Tl beta source.

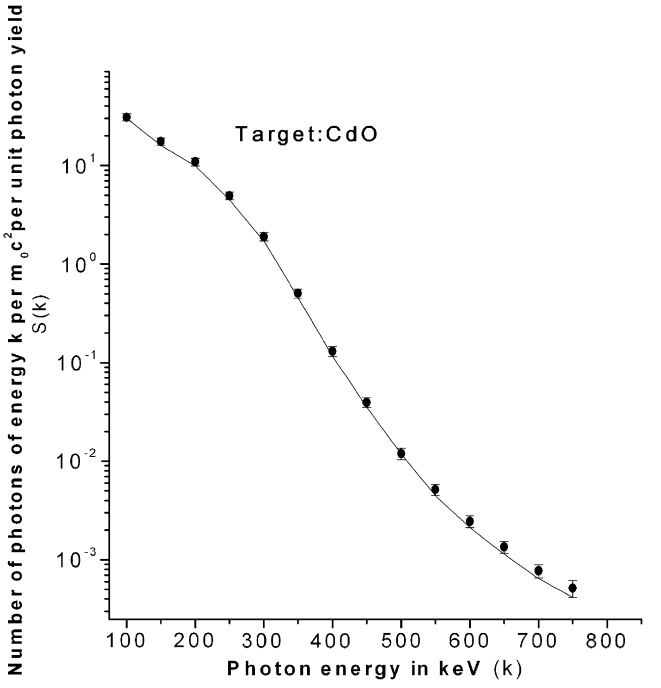

Fig. 3. Unfolded measured EB spectrum(solid squares with error bars) with theoretical spectrum(continues line) of ^{204}Tl beta source.

as follows:

$$S(k) = \left\{ \int_T^{T_{\max}} n(T,k)P(T)\,\mathrm{d}T \right\} \Big/ \left\{ \int_T^{T_{\max}} P(T)\,\mathrm{d}T \right\} \quad (4)$$

here $P(T)$ is the beta spectrum which has been evaluated using kurie plot [12]. The estimated Z' values for target compounds such as PbCl2 and CdO are given by 73.48 and 42.29, respectively The results of $\sigma(E, k)$ evaluated from (1) for various energies have been incorporated in (3) and $S(k)$ is then evaluated using (4) as well as the evaluated theoretical $P(T)$.

2. Results and discussions

The unfolded measured spectra obtained for $PbCl_2$ and CdO along with the evaluated theoretical spectra are shown in Figs. 2 and 3 for the energy range 100–700 keV. The main contribution to the error in the measured spectra comes from counting statistics. This error is estimated to be varies between 2% at low photon energy, to about 16% at high energy. The other contribution to the error comes from Compton electron contribution which varies from 1% to about 3%. The error involved in the estimation of crystal detection is partly due to the uncertainty in the values of absorption coefficients for sodium iodide and partly due to inaccuracy in the experimental determination of peak to total ratios. The error in the values of crystal detection efficiency varies from 1% to about 6%.The overall error in the present measurement is found to varies from 9% to about 24% .In conclusion, experimental results show fairly good agreement at low energy end and disagreement at higher energy with the theory.

References

[1] Sommerfeld, Ann. Phys. (NY) 11 (1931) 256.
[2] H. Bethe, W. Heitler, Proc. R. Soc. London, Ser. A 14 (1934) 83.
[3] F. Sauter, Ann. Phys. (NY) 20 (1934) 404.
[4] G. Racah, Nuovo Cimento 11 (1934) 469.
[5] H.K. Tseng, R.H. Pratt, Phys. Rev. A 3 (1971) 100.
[6] S. S. Martin, J. Berger, At. Data Nucl. Data Tables 35 (1986) 345.
[7] T.B. Vander Wood, J.G. Pearson, P.R. Buseck, Proceedings of the Annual Conference—Microbeam Anal. Soc. 18(1983) 85.
[8] A.A. Markowicz, R.E. VanGriken, Anal. Chem. 56 (1984) 2049.
[9] Shivaramu, J. Appl. Phys. 68 (1) (1990) 1225.
[10] M. Uchiyama, H. Narita, M. Makino, H. Sekine, Y. Mori, N. Fukumitsu, K. Kawakami, Clin. Nucl. Med. 22 (9) (1997) 605.
[11] G.T. Chapman, Nucl. Instr. and Meth. 52 (1967) 101.
[12] M.K. Ragavendra, Internal Bremsstrahlung studies of ^{204}Tl and ^{147}Pm in the 5 to 35 keV region and Coincident measurement of IB on ^{57}Co, Ph.D Thesis, Bangalore university, Bangalore.
[13] B. Rudraswamy, K. Gopala, K.S. Gundu Rao, P. Venkataramaiah, H. Sanjeevaiah, Phys. Rev. A 28 (5) (1983) 2802.
[14] N. Starfelt, Svantesson, Phys. Rev. 97 (1955) 708.