Asian Journal of Chemistry Vol. 18, No. 5 (2006), 3432-3436

Bremsstrahlung Spectral Photon Energy Distributions in Thick Targets

A.S. DHALIWAL
Department of Physics, Sant Longowal Institute of Engineering and Technology, Longowal-148 106, India

The Z-dependence of spectral photon energy distributions of external bremsstrahlung(EB) produced by ^{99}Tc beta particles in thick target, have been studied as a function of photon energy. The present results show that the values of the Z-dependence index, obtained from Bethe and Heitler, Elwert corrected Behe and Heitler, and Tseng and Pratt theories, are not constant. The proportionality factor shows an exponential decaying dependency on the photon energy.

Key Words: Bremsstrahlung, Z-Dependence, Beta particles.

INTRODUCTION

External bremsstrahlung (EB) is a continuous electromagnetic radiation arises from the Coulomb interaction of the fast moving charged particles with target nuclei. The design and utilization of the X-ray machines requires reliable information about the bremsstrahlung spectra from thick targets. The external bremsstrahlung (EB) spectra, generated by complete absorption of beta particles in thick metallic targets, have been studied by various workers. It is also important to know the dependence of spectral shapes on atomic number (Z) of the target at various electron and photon energies. Z-dependence of the EB cross section, at various electron energies and for different metallic targets, has been reported by Hippler *et al*[1] and Semaan and Quarles[2]. They found that the theories of bremsstrahlung are adequate for describing the variation of EB cross section with the electron energies and the atomic number (Z) of the target. The total EB photon yield and total bremsstrahlung energy yield per beta particle are linear functions of the atomic number (Z) of the target[3]. Evans[3] has reported that the shape of bremsstrahlung spectrum is independent of the target number (Z) for continuous beta particles and each beta emitter has its own characteristic EB spectrum. In the previous papers[4-5] the author has studied the shapes of the EB spectra produced by continuous beta particles of ^{147}Pm, ^{170}Tm and ^{32}P beta emitters in different target materials, as a function of photon energy k. In order to investigate the Z-dependence of the spectral shapes of EB, the $S(k,Z)$ *i.e.* the number of photons of energy k per m_0c^2 per beta disintegration, at the photon energy k and as a function of Z can be written as:

$$S(k,Z) = K(k)Z^n \qquad (1)$$

Where 'n' is the index of the Z-dependence of a photon energy k per m_0c^2 per beta disintegration and $K(k)$ is a proportionality factor, which is independent of Z at a particular photon energy k. In the present paper, the shapes of the theoretical EB spectral photon energy distributions produced by ^{99}Tc beta particles, in various target materials have been reported.

THEORETICAL CONSIDERATIONS

Bethe and Heitler[6] have obtained the expression for EB cross section $\sigma_{BH}(k,W_e,Z)$ by neglecting the Coulomb field effects of the nucleus on the incident and scattered electrons. Here k is the photon energy, W_e is the incident electron kinetic energy, and Z is the atomic number of the target material. Elwert[7] found multiplicative Coulomb correction factor for the Bethe and Heitler cross-section from the comparison of the non-relativistic dipole approximation and non-relativistic Sommerfeld calculations. Later Tseng and Pratt[8] developed a theory to calculate the EB cross sections for relativistic electrons using the (screened) self-consistent field wave functions.

The various EB theories give the photon energy distributions for mono-energetic electron incident on thin target. Bethe and Heitler gave an expression for EB spectral photon energy distribution in a sufficiently thick target to absorb an electron of energy $W_e^{/}$ and having N atoms per unit volume. The number of EB photons of energy k are given by

$$n(W_e^{/} = N \int_{1+k}^{W_e^{/}} \frac{d\sigma / dk}{(-dW_e / dx)} dW_e \qquad (2)$$

where $(-dW_e / dx)$ is the total energy loss per unit path length of an electron in the target. This includes the energy lost by the electron due to its inelastic and radiative collisions with an atom. In the case of beta emitter with an end point energy $W_{\max}$, the bremsstrahlung spectrum is given by $S(k,Z)$ *i.e.* the number of photons of energy k per unit energy interval (in m_0c^2) per beta disintegration,

$$S(k,Z) = \int_{1+k}^{W_{\max}} n(W_e^{/},k) P(W_e^{/}) dW_e^{/} \qquad (3)$$

Where $P(W_e^/)dW_e^/$ is the spectrum of beta emitter under study. The factors comprising $S(k,Z)$ *i.e.* number of photons of energy k per m_0c^2 per beta disintegration, do not exhibit clearly its dependence on the atomic number (Z) of the target.

Theoretical EB spectral photon energy distributions, produced by ^{99}Tc beta particles in Al, Cu, Sn and Pb targets were evaluated by using eqs.(2-3). The cross section $d\sigma(k,W_e,Z)/dk$ for Bethe and Heitler (BH) theory, Elwert corrected Bethe and Heitler (EBH) theory, and Tseng and Pratt(TP) theory were used. The values of the total electron energy loss $(-dW_e/dx)$ were taken from the tabulations of Berger and Seltzer[9].

The Z-dependence index 'n' values were calculated at different photon energies for BH theory, EBH theory, and Tseng and Pratt theory by using the ^{99}Tc beta particles. The least square power function fitting Computer program was used to obtain the index values at different photon energies. Values of the index 'n' of the Z-dependence of the EB production as a function of photon energy k/k_{max} are given in table 1.

TABLE-1
THE INDEX n OF THE Z-DEPENDENCE OF THE EB PRODUCTION AS A FUNCTION OF PHOTON ENERGY k/k_{max} FOR ^{99}Tc BETA PARTICLES (k_{max} = 292 keV)

Photon energy (k/k_{max})	Values of index 'n'		
	BH theory	EBH theory	TP theory
0.171	1.068	1.127	1.226
0.308	1.156	1.202	1.311
0.445	1.170	1.314	1.416
0.582	1.210	1.334	1.454
0.719	1.219	1.403	1.576
0.856	1.215	1.425	1.540

The proportionality factor $K(k)$ values in terms of $S(k,Z)$ for BH, EBH and TP theories, at different photon energies were evaluated by using the calculated Z-dependence indices in different target materials. Plot of proportionality factor $K(k)$ *vs.* photon energy k for Tseng and Pratt theory is shown in Fig. 1. The values of proportionality factor $K(k)$ at different photon energies for BH, EBH and TP theories are given in table 2.

TABLE- 2
PROPORTIONALITY FACTOR $K(k)$ AT DIFFERENT PHOTON ENERGIES FOR ^{99}Tc BETA PARTICLES

Photon energy $k\,(keV)$	Proportionality factor $K(k)$		
	BH theory	EBH theory	TP theory
50	1.201×10^{-3}	1.174×10^{-3}	1.007×10^{-3}
90	1.761×10^{-4}	2.063×10^{-4}	1.782×10^{-4}
130	4.218×10^{-5}	3.840×10^{-5}	3.586×10^{-5}
170	8.468×10^{-6}	9.353×10^{-6}	8.842×10^{-6}
210	1.324×10^{-6}	1.426×10^{-6}	1.231×10^{-6}
250	8.186×10^{-8}	1.050×10^{-7}	1.395×10^{-7}

RESULTS AND DISCUSSION

It is clear from the present studies for ^{99}Tc beta particles that the Z-dependence indices, given in table 1, are not constant. Index 'n' for the atomic number (Z) increases slowly with increasing photon energy. This reveals the dependence of the spectral shapes of EB spectra at different photon energies on the atomic number (Z) of the target material.

Fig. 1 indicates the exponential variation of proportionality factor $K(k)$ with photon energy k. The exponential function $\exp[(-4.34\times10^{2}\times k)]$ fits the exponential curves showing the variation of $K(k)$ with k for BH, EBH and TP theories. The variation of index 'n' of Z may be due to the radiative part of the total electron energy loss in a material media. The energy loss due to inelastic collisions is dependent on Z whereas the radiative loss due to which the bremsstrahlung is produced has a mild dependence on the atomic number (Z) of the target material.

The variation of proportionality factor $K(k)$ with photon energy k is due to the continuous loss of energy by the electrons in the target as the EB spectral photon energy distributions are obtained on the basis of continuous slowing down approximation (CSDA). In a thick target, the hard beta particles loss more energy than a soft beta particles, so the target thickness acts as an energy filter. The transmitted EB spectrum is rich in high energy photons relative to low energy photons. The present studies indicate that the spectral shapes of EB spectra as a function of photon energy depends on the Z-value of the target material.

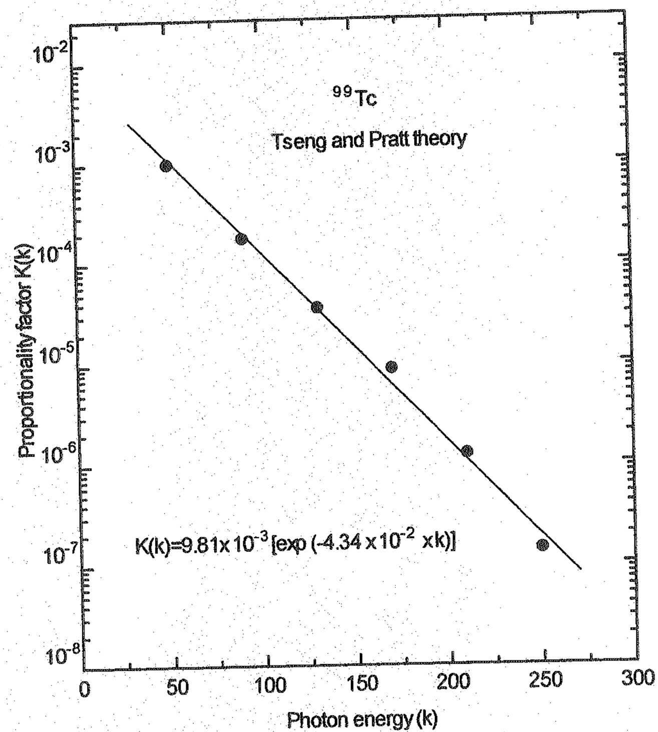

Fig.1. Plot of proportionality factor K(k) *vs.* photon energy k. Symbols are the data points and the line is a fit to the points

REFERENCES

1. R. Hippler, K. Saeed, I. McGregor and H. Kleinpoppen, *Phys. Rev. Lett.*, **46**, 1622 (1981).
2. M.Semaan and C.A. Quarles, *Phys. Rev. A*, **26**, 3152 (1982).
3. R.D. Evans, *Phys.Rev*, **59**, 481(1941).
4. A.S. Dhaliwal, *J.Phys. B: At. Mol. Opt. Phys.*, **36**, 2229 (2003).
5. A.S. Dhaliwal, *Nucl. Instru. Methods Phys. Res. B*, **234**, 194(2005).
6. H.Bethe and W Heitler, *Proc. Royal. Soc. A*, **146**, 83 (1934).
7. G. Elwert, *Ann. Phys.*, **34**, 178 (1939).
8. H.K. Tseng and R.H. Pratt, *Phys. Rev. A*, **3**,100 (1971).
9. M.J. Berger and M. Seltzer, National Bureau of Standards Internal Report No. 82-2550A (1982).