Studies of total bremsstrahlung spectra from ^{89}Sr beta particles in Mo and Pt metallic targets in photon energy region of 1-100 keV

Amrit Singh[1,a] and A S Dhaliwal[2]

[1] *Department of Physics, Mata Gujri College, Fatehgarh Sahib, Punjab, INDIA*
[2] *Department of Physics, SLIET, Longowal, Punjab, INDIA*

Abstract. Total bremsstrahlung spectra in thick targets of Mo and Pt, produced by beta emitter ^{89}Sr (end point energy = 1464 keV) have been studied in the photon energy range of 1-100 keV. The experimentally measured spectra measured were compared with the theoretical spectral distributions calculated from Elwert corrected (non relativistic) Bethe-Heitler [EBH] theory, modified Elwert factor (relativistic) Bethe-Heitler (F_{mod} BH) theory for ordinary bremsstrahlung (OB) and the modified Elwert factor (relativistic) Bethe-Heitler (F_{mod} BH+PB) theory, which includes the polarization bremsstrahlung (PB) into total bremsstrahlung (BS). The present results indicate the correctness of F_{mod} BH+PB theory in the low energy region, where the contributions of PB into BS are dominant. But at the middle and higher energy region of the bremsstrahlung spectrum, where the contribution of PB is negligible, the F_{mod} BH theory is more close to the experimental results.

1 Introduction

The bremsstrahlung process is an outcome of general coupling of the electromagnetic and matter fields. This process has wide range of applications in all branches of physics: atomic and molecular physics, nuclear physics, solid-state and elementary-particle physics, astrophysics, material characterization etc. The bremsstrahlung process is further divided into ordinary bremsstrahlung (OB) and polarization bremsstrahlung (PB). OB is the process by which the photon is emitted by the electron decelerating in the static field of the target atom and in PB, dynamic response of the target atom has been considered and the photon emitted by target as a result of its polarization by incident electron. The sum of the amplitudes of OB and PB forms the total bremsstrahlung (BS).

Bethe and Heitler [1] gave the basic theory for OB by using Born approximation and later this theory was corrected by Elwert [2] for non-relativistic case. Tseng and Pratt [3] also gave a theory for OB by using the self consistent field wave functions and claimed that their theory is more accurate than the other available theories. Koch and Motz [4], Pratt and Feng [5], Seltzer and Berger [6] and Pratt et al. [7] have given the general reviews on the theory of OB.

Tystovich and Ojringel [8], Korol and Solov'yov [9], Korol et al. [10], Korol and Solov'yov [11] and Amusia [12,13] reviewed the theoretical and experimental studies of polarization bremsstrahlung in detail. The dynamic response of the target atom and the atomic dynamic polarizability is considered necessary for the calculation of PB amplitude. The equivalent methods for the bremsstrahlung spectra, having contributions of OB and PB, are described by Korol et al. [14] and Avdonina and Pratt [15] by using the stripped atom (SA) approximation. These studies shall be useful to check the correctness of various theoretical models for OB and BS processes, and may further define the energy region upto which the PB contributes into the bremsstrahlung spectrum formation for Mo and Pt metallic targets.

2 Theory

Avdonina and Pratt [15] included the modified relativistic Elwert factor (F_{mod}) in Bethe-Heitler cross-sections for the bremsstrahlung spectrum in a target and described the bremsstrahlung energy spectrum in the form of Gaunt factor $G_{OB}(W_e,k,Z)$, which depends upon the incident electron energy (W_e), the energy of the emitted photon (k) and the atomic number (Z) of the target material,

$$G_{OB}(W_e,k,Z)=G_{BH}(W_e,k,Z)F_{mod}C(T_i,Z) \qquad (1)$$

Here, $G_{BH}(W_e,k,Z)$ is a Gaunt factor for Bethe-Heitler cross-section and $C(T_i,Z)$ is a higher order Born approximation factor. Here, T_i is the initial electron kinetic energy and α is the fine structure constant. Further, they described the BS spectrum for a screened Coulomb potential for atoms and ions for soft and hard photon energy regions in which PB is incorporated into OB by using SA approximation. An analytical expression for soft and hard photon energy region of the BS energy spectrum is given by $G_{BS}(W_e,k,Z)$,

[a] Corresponding author: amritsliet@gmail.com

$$G_{BS}(W_e,k,Z)=G_B(W_e,k,Z)-\frac{\sqrt{3}}{\pi}\ln\left(\frac{q_+}{q_-}\right)+G_{OB}(W_e,k,Z) \quad (2)$$

Here, the first term $G_B(W_e,k,Z)$ is the bremsstrahlung energy spectrum in the Born approximation with screening parameter. Here $q_\pm = p_i \pm p_f$ is the maximum and minimum momentum transfer. Further, the third term represents the bremsstrahlung energy spectrum in a pure Coulombic case.

In order to calculate the bremsstrahlung energy spectrum, Bethe-Heitler gave an expression $n(W_e^/,k,Z)$ for a target with N number of atoms per unit volume to absorb a mono-energetic electron of energy $W_e^/$

$$n(W_e^/,k,Z)=N\int_{1+k}^{W_e^/}\frac{d\sigma(W_e,k,Z)/dk}{(-dW_e/dx)}dW_e \quad (3)$$

Here $d\sigma(W_e,k,Z)/dk$ is a single bremsstrahlung cross-section in terms of photon energy and $-dW_e/dx$ the total energy loss per unit path length of an electron in a target material. Further, for complete absorption of continuous beta particles with end-point energy W_{max}, the BS spectral photon distribution in an optimum thick target is given by $S(k,Z)$ i.e. the number of photons of energy k per unit m_oc^2 per beta disintegration,

$$S(k,Z)=\int_{1+k}^{W_{max}}n(W_e^/,k,Z)P(W_e^/)dW_e^/ \quad (4)$$

Here $P(W_e^/)dW_e^/$ is the beta spectrum of the beta emitter under study.

The theoretical bremsstrahlung spectra for Mo and Pt targets for ^{89}Sr beta emitter are obtained from Eq. (4). Further, the theoretical distributions are converted into the number of photons of energy k per m_oc^2 for comparison with the experimental results by dividing them with the total photon yield (T) per beta disintegration. The values of T for different target materials are obtained from graphical integration of the BS spectra from the plots of $S(k,Z)$ versus photon energy *k* between k_{min} and k_{max} i.e., 1 keV and 100 keV.

In the present paper, the studies of the formation of the BS energy spectrum, have been reported in the photon energy region of 1-100 keV for ^{89}Sr (W_{max}=1464 keV) beta emitter in thick targets of Mo and Pt. The measurements have been made for Mo and Pt targets for defining the photon energy regions upto which the PB contributes into the BS spectrum formation.

It is expected that the present measurements shall describe the formation of BS spectrum and the contributions of PB in the photon energy region of 1 keV to 100 keV. Further, the importance of SA approximation for the bremsstrahlung energy spectrum at low energy regions can be described.

3 Experimental details

The experimental arrangement, consisting of Si(Li) detector biased through a power supply and coupled to Linear Amplifier and Multichannel analyzer, is used for the measurement of BS spectral photon distributions in Moa and Pt targets. Most of the experimental details are similar to those reported earlier by Singh and Dhaliwal [16]. Measurements are taken for a time interval of 150000 second by placing the target at position A and B. After subtracting the measurements at Position A from the measurements at Position B, the contributions of internal bremsstrahlung, bremsstrahlung generated in the source material, characteristics X-rays, if any, of the element and room background are eliminated from the measurements for obtaining the correct information of the BS originating in a particular thickness target. This difference method of measurement of BS in target materials is useful to reduce the uncertainties in applying the corrections due to Si K X-ray, Ar K X-ray peaks, and Pb X-rays, particularly at low photon energy region.

Further, the corrections due to the response functions of Si(Li) detector are applied to experimentally measured BS spectrum. In the present measurements, the corrections due Si K-ray and Ar K X-ray peaks, backscattering and Compton continuum are found to be negligible for Si(Li) detector in the studied energy region due to geometrical set up and the method of measurement employed here. The overall errors in the present measurements of BS spectra for ^{89}Sr beta emitter are less than 10% in the entire photon energy region of 1-100 keV. These errors are due to the statistics of the data, which is better than 1%, geometrical full-energy peak detection efficiency of detector, which are uncertain by 3% due the errors in the measurement of photo-fractions. The errors involved in the correction due to Compton continuum, backscattering correction and escape peak correction are less than 1%, as the contributions of these corrections are small. The experimental results are expressed in the terms of number of photon of energy k per m_oc^2 and as shown in Fig. 1. Finally for the comparison with the theoretical model the experimental spectrum is divided with total photon yield and expressed in the terms of number of photons of energy k per m_oc^2 per unit photon yield.

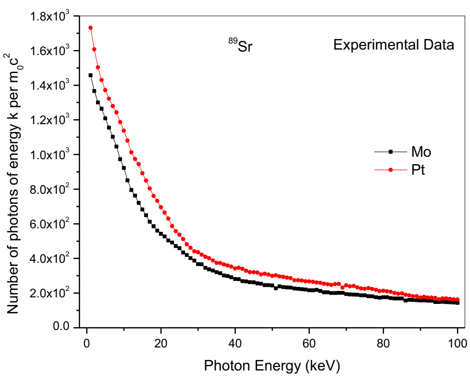


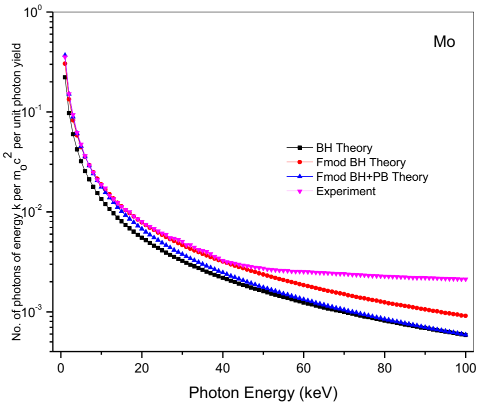
Figure 1. Plots of experimental BS spectrum in terms of photons of energy k per m_oc^2 versus photon energy (*k*) for ^{89}Sr beta particles in photon energy region1-100 keV

4 Results and discussion

The experimentally measured bremsstrahlung spectra of Mo and Pt produced by ^{89}Sr beta particles are compared with the theoretical bremsstrahlung spectral distributions obtained from the EBH and F_{mod} BH theory for OB and F_{mod} BH +PB theory which includes contributions of PB into BS, in the photon energy region of 1 - 100 keV. The plots of number of photons of energy k per m_oc^2 per unit photon yield versus photon energy (k) for Mo and Pt targets are shown in Fig. 2.

The Fig. 2 shows that the experimentally measured BS spectra for Mo target which is in agreement within 8% with (F_{mod} BH +PB) theory up to photon energy of 15 keV and thereafter experimental spectrum is closer to the spectra obtained from F_{mod} BH theory. The variation among the experimental results and the F_{mod} BH+PB theory are is 15% at 20 keV and 85% at 100 keV photon energies. It has been found that the PB contribution decreases from 28% to 1% at 1 keV to 20 keV photon energies respectively. In the case of Pt target, the experimental results are in agreement with the F_{mod} BH+PB theory from 1 keV to 26 keV within 15%. Beyond 12 keV the experimental results are closer to F_{mod} BH theory. The variations of experimental results from F_{mod} BH+PB theory are 25% at 30 keV, 50% at 60 keV to 82% at 100 keV photon energies. In this case, PB contribution decreases from 30% at 1 keV to 1 % at 26 keV photon energies.

The present results show the correctness of the F_{mod} BH+PB theory at lower energy end, where the contributions of PB into BS are prominent. But at the middle and higher energy region of the bremsstrahlung spectrum, the F_{mod} BH theory is more close to the experimental results. It is concluded that the production of PB in the low photon energy region, due to the dynamic response of the target atom suppresses the bremsstrahlung at higher energy ends. Hence, more orderly investigations for bremsstrahlung spectra in metallic targets are required for describing the theoretical results at various photon energies.



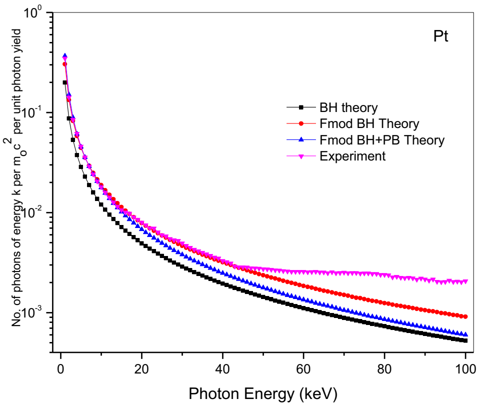


Figure 2. Plots of number of BS photons of energy k per m_oc^2 per unit total photon yield versus photon energy k (keV) for Mo and Pt targets in photon energy region of 1-100 keV

References

1. H. Bethe, W. Heitler, *Proc. Roy. Soc. Lond. A,* **146**, 83 (1934).
2. G. Elwert, *Ann. Phys.* **34**,178 (1939).
3. H. Tseng, R. Pratt, *Phys. Rev. A.* **3**, 100 (1971).
4. H.W. Koch, J.W. Motz, Rev. Mod. Phys. **116**, 920 (1959).
5. R. H. Pratt, I. J. Feng, Electron-atom bremsstrahlung. In Crasemann, B. (Ed), Atomic inner shell physics. Plenum Press, New York, pp. 533-580 (1985). (Chapter 12)
6. S. Seltzer, M. Berger, *Nucl. Inst. Meth. Phys. Res. B.* **12,** 95 (1985).
7. R. Pratt, H. Tseng, C. Lee, L. Kissel, C. MacCallum, M. Riley, *At. Data Nucl. Data Tables.* **20**, 175 (1977).
8. V. Tsytovich, N. Ojringel, I. M. (Eds.) 1993. Polarizational bremsstrahlung. Plenum, NY.
9. A.V. Korol, A.V. Solov'yov, *Rad. Phys. and chem.* 75 : 1266 (2006).
10. A .V Korol, A. G Lyalin, A. V Solovy, N. B Avdonina, R. H. Pratt, *J. Phys. B: At. Mol. Opt. Phys.* **35**, 1197 (2002).
11. A. Korol, A. Solov'yov, *J. Phys. B: At. Mol. Opt. Phys.* **30**, 1105 (1997).
12. M. Amusia, A. Korol, *Nucl. Instr. and Meth. B.* **79**, 146 (1993).
13. M. Amusia, *Rad. Phys. and Chem.* **75**, 1232 (2006).
14. A. Korol, O. Obolensky, A. Solov'yov, I. Solovjev, *J. Phys. B: At. Mol. Opt. Phys.* **34**, 1589 (2001).
15. N. B. Avdonina, R. H. Pratt, *J. Phys. B: At. Mol. Opt. Phys.* **32**, 4261 (1999).
16. A. Singh and A.S. Dhaliwal, *Phy. Lett. A*. **379**, 1127 (2015).