Bremsstrahlung Cross Sections in Ceramic Compounds at Incident Electron Energies (10 kev, 20 kev and 30kev)

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ABSTRACT
Numerical bremsstrahlung cross sections for different ceramic compounds like Alumina (Al_2O_3), beryllia (BeO), ceria (CeO), Zirconia (ZrO_2) were calculated by using Z_{mod} of metallic compounds at different incident electron energies (10 keV,20 keV and 30 keV) in the photon energy regions of energy (1-10 keV,1-20 keV and 1-30 keV). The cross sections were calculated by using Elwert corrected (non relativistic) Bethe Heitler (1934) theory for ordinary bremsstrahlung (OB), modified Elwert factor (relativistic) Bethe Heitler theory for OB and modified Elwert Factor(relativistic) Bethe Heitler theory which includes the polarization Bremsstrahlung (PB) into OB given by Avdonia and Pratt (1999).The effect of effective atomic number of the metallic compounds on the bremsstrahlung cross sections is studied. Comparing the results of above theories the dependence of PB and OB on energy of incident electrons and the energy of emitted photon is studied. The results clearly indicate the importance of PB, particularly in the studied energy regions.

Keywords
Ordinary bremsstrahlung, polarization bremsstrahlung, ceramic compounds, bremsstrahlung cross sections

1. INTRODUCTION
Ordinary bremsstrahlung (OB) is the phenomenon of emission of photons due to the interaction of incident electrons with the coulomb field of static nucleus. OB has been studied theoretically and practically by many researchers at different range of energies of incident electrons and at different energies of emitted photons [Bethe and Heitler [1], Elwert [2], Kotch and Motz [3], Tseng and Pratt [4], Singh et al.[5]. Buimistrov and Trakhtenberg [6] reported that due to the field of electron the behaviour of target atom gets changed and it gets polarized. This phenomenon of emission of energy due to polarization of target atom is termed as polarization bremsstrahlung (PB). The total bremsstrahlung (BS) is the sum of ordinary bremsstrahlung and polarization bremsstrahlung.

There are different theories of calculation of bremsstrahlung cross sections at different range of energies of incident electrons and at different energies of emitted photons. First quantum mechanical cross-section formula for bremsstrahlung was given by Sommerfeld [7] in the non relativistic dipole approximation for non relativistic electrons without considering the effect of nuclear screening. Bethe and Heitler [1] derived expression for OB cross section dσ (We,k,z)/dk by neglecting coulomb field effects on wave functions of incident and scattered electrons on the nucleus by using first order Born approximation. Elwert [2] gave multiplicative coulomb correction factor (F_{elwert}) for Bethe-Heitler OB cross section. Quantum theory for bremsstrahlung for relativistic electrons was given by Tseng and Pratt using screened self consistent field wave function. Pratt et all [8] published extensive tables of OB cross section. The contribution of electron-electron bremsstrahlung to the electron-nucleus bremsstrahlung was given by Seltzer & Berger [9]. Koch & Motz [3] has given extensive reviews of studies of OB.

For non-relativistic electron energies, in the Born approximation, Amusia et al. [10] has described that PB can be added with OB in a stripped atom approximation (SAA). Avdonina and Pratt [11] have given the equivalent method for the total Bremsstrahlung spectra in the stripped atom approximation (SAA), which is efficient for obtaining the BS spectra for photon energies greater than the ionization potential of the outer shell electrons of the target atom. In SAA, the decrease of OB due to screening of outer shell electrons is completely compensated by additional PB produced by the same outer shell electrons.

Avdonina and Pratt [11] modified the Elwert corrected (non-relativistic) Bethe and Heitler [1] theory for OB and described the BS spectra i.e. (OB + PB) over a wide range of photon energies by applying the SAA. They further described that in the non-relativistic case PB decreases with increasing photon energy in the same way as the screening contribution to OB, leading to the Columbic behaviour of the spectrum.

The theories discussed above are applicable to thin target OB or BS spectra only, in which the mono-energetic electron has only a single radiative interaction. In the case of a thick target, processes such as electron scattering, excitation and ionization that compete with Bremsstrahlung must be taken into account.

Most of bremsstrahlung (BS) work of beta particles has been done on the metal as a thick target, but using compound as a thick target is rarely available. Some work is available in metallic compounds to study the relation between Zeff of compounds and Bremsstrahlung [Manjunatha et al.[12], Manjunatha and Rudraswamy [13].

Present study is technique to apply the existing theory to ceramic compounds and to focus on various compounds which can be used as targets for incident beta particles to produce BS spectrum. This method provides a Comparison of theoretical results at different energies of incident electrons and at different photon energies. In the present study, ceramic compounds Alumina (Al_2O_3), beryllia (BeO), ceria (CeO), Zirconia(ZrO_2) have been used.

2. METHODOLOGY
In the present work, Zmod has been calculated from the formula

$$Zmod=\frac{\sum_i^l \frac{w_i z_i^2}{A_i}}{\sum_i^l \frac{w_i z_i}{A_i}}$$

Zmod- The modified effective atomic no. Of metallic compound

W_i, Z_i, A_i- weight fraction, atomic weight and atomic no. of ith element in the compound.

The expression for ordinary Bremsstrahlung cross section in born's approximation is called Bethe –Heitler formula. The Bethe–Heitler OB cross section($\sigma_{BH}(W_{e,K,Z})$ differential in photon energy k is given as,

$$\sigma_{BH}(W_{e,K,Z})=\frac{Z^2 r_0^2}{137}\frac{dk}{k}\frac{P}{P_e}\left[\frac{4}{3}-2W_eW\frac{P_e^2+P^2}{P_e^2P^2}+\frac{E_eW}{P_e^3}+\frac{E_eW_e}{P^3}-\frac{E_eE}{P_eP}+L(A+B)\right]$$

W_e,W=initial and final total energy of electron

P_e,P=initial and final momentum of electron

The multiplicative coulomb correction factor (F_{elwert}) for Bethe-Heitler OB cross section is given as

$$F_{elw}=\frac{W/P[1-\exp(-2\pi\alpha Z(2\pi\alpha ZW_e/P_e)]}{W_e/P_e[1-\exp(-2\pi\alpha ZW/P)]}$$

T_{if} =initial and final kinetic energy

Modified elewert factor is given as

$$F_{mod}=\left[\frac{P_i(1-\exp(-2\pi Z/\alpha P_i)}{P_f(1-\exp(-2\pi Z/\alpha P_f)}\right]$$

Corrected modified OB cross section $\sigma_{cor}(W_{e,k,Z}))$ is given by

$$\sigma_{cor}(w_e,k,z)) = C(T_i,Z)\,F_{mod}\,\sigma_{BH}(w_{e,K,Z})$$

Further Avdonina and Pratt has proposed an expression for cross section which includes polarization Bremsstrahlung in SAA with ordinary Bremsstrahlung

$$\sigma(W_{e,K,Z}) = \sigma_B(k) - \frac{\sqrt{3}}{\pi}\ln\frac{q_+}{q_-}+\sigma_{cor}(w_{e,K,Z})$$

3. RESULTS AND DISCUSSIONS

Programmes were written to calculate the Bremsstrahlung cross sections theoretically at different energy range of incident electron and at different range of energy of emitted photons using the theories of Bethe–Hietler [1] Bethe-Heitler corrected theory [2] and Avdonina and Pratt [11] expression.

From the theoretical results calculated below (Table 1-4), we see that there is visible effect of PB in ceramic compounds at lower value of emitted photon energies and this effect goes on reducing as energy of emitted photon goes on increasing .Further this effect also decreases with the increase in energy of incident electrons. Similarly it is observed that PB effect is slightly more in compounds having more Zmod. So there is need to study the effect of PB in ceramic compounds at low energy theoretically and experimentally in detail and the effect of Zmod and energy of emitted photon on the PB is also needed to study theoretically and experimentally in different energy regions. Bremsstrahlung studies are an important tool in studying various phenomenons in atomic physics, nuclear physics, plasma physics, astro physics and solid state physics. PB theory is a base for certain phenomenon like transient, transient resonance, diffraction emissions.

Table 1. Bremsstrahlung cross section table for Al_2O_3 (Alumina) compound at 10 Kev incident electron energy In the range of 1-10 kev,1-20 keV,1-30 keV photon energy (Zmod= 10.598)

Te=10 keV				
K	σ_{mod} $(W_{e,k,Z})$	σ_{cor} $(W_{e,k,Z}))$	$\sigma(W_{e,K,Z})$+PB	Deviation= $\sigma(W_{e,K,Z})$+PB - $\sigma_{cor}(W_{e,k,Z})$
1	1.79×10^{-20}	1.79×10^{-20}	3.79×10^{-20}	2.00×10^{-20}
2	7.59×10^{-21}	7.62×10^{-21}	9.2×10^{-21}	1.59×10^{-21}
3	4.61×10^{-21}	4.62×10^{-21}	5.95×10^{-21}	1.33×10^{-21}
4	3.27×10^{-21}	3.28×10^{-21}	4.41×10^{-21}	1.13×10^{-21}
5	2.57×10^{-21}	2.58×10^{-21}	3.55×10^{-21}	0.97×10^{-21}
6	2.22×10^{-21}	2.22×10^{-21}	3.04×10^{-21}	0.82×10^{-21}
7	2.15×10^{-21}	2.15×10^{-21}	2.82×10^{-21}	0.67×10^{-21}
8	2.56×10^{-21}	2.57×10^{-21}	3.1×10^{-21}	0.53×10^{-21}
9	5.21×10^{-21}	5.22×10^{-21}	5.58×10^{-21}	0.36×10^{-21}
Te=20 keV				
2	4.56×10^{-21}	4.58×10^{-21}	6.57×10^{-21}	1.99×10^{-21}
4	1.93×10^{-21}	1.94×10^{-21}	3.52×10^{-21}	1.58×10^{-21}
6	1.17×10^{-21}	1.17×10^{-21}	2.49×10^{-21}	1.32×10^{-21}
8	8.29×10^{-22}	8.31×10^{-22}	9.44×10^{-22}	1.13×10^{-22}
10	6.51×10^{-22}	6.53×10^{-22}	7.49×10^{-22}	0.96×10^{-22}
12	5.60×10^{-22}	5.61×10^{-22}	6.42×10^{-22}	0.81×10^{-22}
14	5.41×10^{-22}	5.43×10^{-22}	6.1×10^{-22}	0.67×10^{-22}
16	6.46×10^{-22}	6.49×10^{-22}	7.01×10^{-22}	0.52×10^{-22}
18	1.32×10^{-21}	1.32×10^{-21}	1.68×10^{-21}	3.00×10^{-21}
T_e=30 keV				
3	2.07×10^{-21}	2.07×10^{-21}	4.06×10^{-21}	1.99×10^{-21}
6	8.73×10^{-22}	8.76×10^{-22}	10.34×10^{-22}	1.58×10^{-22}
9	5.27×10^{-22}	5.29×10^{-22}	6.61×10^{-22}	1.32×10^{-22}
12	3.73×10^{-22}	3.74×10^{-22}	4.87×10^{-22}	1.13×10^{-22}
15	2.92×10^{-22}	2.93×10^{-22}	3.89×10^{-22}	0.96×10^{-22}
18	2.51×10^{-22}	2.51×10^{-22}	3.32×10^{-22}	0.81×10^{-22}
21	2.42×10^{-22}	2.43×10^{-22}	3.10×10^{-22}	0.67×10^{-22}
24	2.90×10^{-22}	2.90×10^{-22}	3.43×10^{-22}	0.53×10^{-22}
27	5.94×10^{-22}	5.95×10^{-22}	6.31×10^{-22}	0.36×10^{-22}

Table 2. Bremsstrahlung cross section table for ceria (CeO_2) compound at 10 Kev incident electron energy In the range of 1-10 kev,1-20 keV,1-30 keV photon energy Zmod= 47.17

Te=10 keV				
k	σ_{mod} $(W_{e,k,Z})$	σ_{cor} $(W_{e,k,Z}))$	$\sigma(W_{e,K,Z})$+ PB	Deviation= $\sigma(W_{e,K,Z})$+PB - $\sigma_{cor}(W_{e,k,Z})$
1	3.54×10^{-19}	3.75×10^{-19}	5.75×10^{-19}	2.0×10^{-19}
2	1.50×10^{-19}	1.59×10^{-19}	3.17×10^{-19}	1.58×10^{-19}
3	9.13×10^{-20}	9.66×10^{-20}	10.99×10^{-20}	1.33×10^{-20}
4	6.48×10^{-20}	$6.87\times10^{-}$	8×10^{-20}	1.13×10^{-20}

		20		
5	5.10×10^{-20}	5.40×10^{-20}	6.37×10^{-20}	0.97×10^{-20}
6	4.39×10^{-20}	4.65×10^{-20}	5.47×10^{-20}	0.82×10^{-20}
7	4.25×10^{-20}	4.50×10^{-20}	5.17×10^{-20}	0.67×10^{-20}
8	5.08×10^{-20}	5.37×10^{-20}	5.9×10^{-20}	0.53×10^{-20}
9	1.03×10^{-19}	1.09×10^{-19}	1.45×10^{-19}	0.36×10^{-19}
Te=20 keV				
2	9.04×10^{-20}	9.56×10^{-20}	11.55×10^{-20}	1.99×10^{-19}
4	3.82×10^{-20}	4.05×10^{-20}	5.63×10^{-20}	1.58×10^{-19}
6	2.32×10^{-20}	2.45×10^{-20}	3.77×10^{-20}	1.32×10^{-20}
8	1.64×10^{-20}	1.74×10^{-20}	2.86×10^{-20}	1.12×10^{-20}
10	1.29×10^{-20}	1.36×10^{-20}	2.32×10^{-20}	0.96×10^{-20}
12	1.11×10^{-20}	1.17×10^{-20}	1.99×10^{-20}	0.82×10^{-20}
14	1.07×10^{-20}	1.13×10^{-20}	1.8×10^{-20}	0.67×10^{-20}
16	1.28×10^{-20}	1.35×10^{-20}	1.87×10^{-20}	0.52×10^{-20}
18	2.61×10^{-20}	2.76×10^{-20}	3.12×10^{-20}	0.36×10^{-20}
T_e=30 keV				
3	4.10×10^{-20}	4.33×10^{-20}	6.32×10^{-20}	1.99×10^{-20}
6	1.73×10^{-20}	1.83×10^{-20}	3.41×10^{-20}	1.58×10^{-20}
9	1.04×10^{-20}	1.10×10^{-20}	2.42×10^{-20}	1.32×10^{-20}
12	7.39×10^{-21}	7.81×10^{-21}	8.93×10^{-21}	1.12×10^{-21}
15	5.79×10^{-21}	6.12×10^{-21}	7.08×10^{-21}	0.96×10^{-21}
18	4.97×10^{-21}	5.26×10^{-21}	6.07×10^{-21}	0.81×10^{-21}
21	4.80×10^{-21}	5.08×10^{-21}	5.75×10^{-21}	0.67×10^{-21}
24	5.75×10^{-21}	6.08×10^{-21}	6.6×10^{-21}	0.52×10^{-21}
27	1.18×10^{-20}	1.24×10^{-20}	1.6×10^{-20}	0.36×10^{-20}

Table 3. Bremsstrahlung cross section table for zirconia (ZrO_2) compound at 10 Kev incident electron energy In the range of 1-10 kev, 1-20 keV, 1-30 keV photon energy (Zmod=30.88)

Te=10 keV				
K	σ_{mod} $(W_{e,k,Z})$	σ_{cor} $(W_{e,k,Z}))$	$\sigma(W_{e,K,Z})$+ PB	Deviation= $\sigma(W_{e,K,Z})$+PB - $\sigma_{cor}(W_{e,k,Z})$
1	1.52×10^{-19}	1.55×10^{-19}	3.55×10^{-19}	2.0×10^{-19}
2	6.45×10^{-20}	6.61×10^{-20}	8.2×10^{-20}	1.59×10^{-20}
3	3.91×10^{-20}	4.01×10^{-20}	5.34×10^{-20}	1.33×10^{-20}
4	2.78×10^{-20}	2.85×10^{-20}	3.98×10^{-20}	1.13×10^{-20}
5	2.19×10^{-20}	2.24×10^{-20}	3.21×10^{-20}	0.97×10^{-20}
6	1.88×10^{-20}	1.93×10^{-20}	2.75×10^{-20}	0.82×10^{-20}
7	1.82×10^{-20}	1.87×10^{-20}	2.54×10^{-20}	0.67×10^{-20}
8	2.18×10^{-20}	2.23×10^{-20}	2.76×10^{-20}	0.53×10^{-20}
9	4.42×10^{-20}	4.53×10^{-20}	4.89×10^{-20}	0.36×10^{-20}
Te=20 keV				
2	3.87×10^{-20}	3.97×10^{-20}	5.96×10^{-20}	1.99×10^{-20}
4	1.64×10^{-20}	1.68×10^{-20}	3.26×10^{-20}	1.58×10^{-20}
6	9.93×10^{-21}	10.1×10^{-21}	11.42×10^{-20}	1.32×10^{-20}
8	7.04×10^{-21}	7.21×10^{-21}	8.34×10^{-20}	1.13×10^{-20}
10	5.52×10^{-21}	5.66×10^{-21}	6.62×10^{-20}	0.96×10^{-20}
12	4.75×10^{-21}	4.87×10^{-21}	5.68×10^{-20}	0.81×10^{-20}
14	4.59×10^{-21}	4.71×10^{-21}	5.38×10^{-20}	0.67×10^{-20}
16	5.49×10^{-21}	5.63×10^{-21}	6.15×10^{-20}	0.52×10^{-20}
18	1.12×10^{-20}	1.15×10^{-20}	1.51×10^{-20}	0.36×10^{-20}
T_e=30 keV				
3	4.10×10^{-20}	4.33×10^{-20}	6.32×10^{-20}	1.99×10^{-20}
6	1.73×10^{-20}	1.83×10^{-20}	3.41×10^{-20}	1.58×10^{-20}
9	1.04×10^{-20}	1.10×10^{-20}	2.42×10^{-20}	1.32×10^{-20}
12	7.39×10^{-21}	7.81×10^{-21}	8.93×10^{-21}	1.12×10^{-21}
15	5.79×10^{-21}	6.12×10^{-21}	7.08×10^{-21}	0.96×10^{-21}
18	4.97×10^{-21}	5.25×10^{-21}	6.06×10^{-21}	0.81×10^{-21}
21	4.80×10^{-21}	5.08×10^{-21}	5.75×10^{-21}	0.67×10^{-21}
24	5.75×10^{-21}	6.08×10^{-21}	6.6×10^{-21}	0.52×10^{-21}
27	1.17×10^{-20}	1.24×10^{-20}	1.6×10^{-20}	0.36×10^{-20}

Table 4. Bremsstrahlung cross section table for beryllia(BeO) compound at 10 Kev incident electron energy In the range of 1-10 kev,1-20 keV,1-30 keV photon energy Zmod= 6.66

K	σ_{mod} $(W_{e,k,Z})$	σ_{cor} $(W_{e,k,Z})$	$\sigma(W_{e,K,Z})$+PB	Deviation= $\sigma(W_{e,K,Z})$+PB - $\sigma_{cor}(W_{e,k,Z})$
Te=10 keV				
1	7.06×10^{-21}	7.07×10^{-21}	9.07×10^{-21}	2.0×10^{-21}
2	3.00×10^{-21}	3.0×10^{-21}	4.59×10^{-22}	1.59×10^{-22}
3	1.82×10^{-21}	1.82×10^{-21}	3.15×10^{-22}	1.33×10^{-22}
4	1.29×10^{-21}	1.29×10^{-21}	2.42×10^{-22}	1.13×10^{-22}
5	1.01×10^{-21}	1.02×10^{-21}	1.99×10^{-22}	0.97×10^{-22}
6	8.76×10^{-22}	8.77×10^{-22}	9.59×10^{-22}	0.82×10^{-22}
7	8.48×10^{-22}	8.49×10^{-22}	9.16×10^{-22}	0.67×10^{-22}
8	1.01×10^{-21}	1.01×10^{-21}	1.54×10^{-22}	0.53×10^{-22}
9	2.06×10^{-21}	2.06×10^{-21}	2.42×10^{-21}	0.36×10^{-21}
Te=20 keV				
2	1.80×10^{-21}	1.80×10^{-21}	3.79×10^{-21}	1.99×10^{-21}
4	7.63×10^{-21}	7.63×10^{-21}	9.21×10^{-21}	1.58×10^{-21}
6	1.82×10^{-21}	4.62×10^{-21}	5.94×10^{-21}	1.32×10^{-21}
8	1.29×10^{-21}	3.28×10^{-21}	4.41×10^{-21}	1.13×10^{-21}
10	1.01×10^{-21}	2.57×10^{-21}	3.53×10^{-21}	0.96×10^{-21}
12	8.76×10^{-22}	2.21×10^{-22}	3.02×10^{-22}	0.81×10^{-22}
14	8.48×10^{-22}	2.14×10^{-22}	2.81×10^{-22}	0.67×10^{-22}
16	1.01×10^{-21}	2.56×10^{-22}	3.09×10^{-22}	0.53×10^{-22}
18	2.06×10^{-21}	5.21×10^{-21}	5.57×10^{-21}	0.36×10^{-21}
T_e=30 keV				
3	8.17×10^{-22}	8.18×10^{-22}	10.17×10^{-22}	1.99×10^{-22}
6	3.45×10^{-22}	3.45×10^{-22}	5.03×10^{-22}	1.58×10^{-22}
9	2.08×10^{-22}	2.08×10^{-22}	3.4×10^{-22}	1.32×10^{-22}
12	1.47×10^{-22}	1.47×10^{-22}	2.6×10^{-22}	1.13×10^{-22}
15	1.15×10^{-22}	1.15×10^{-22}	2.11×10^{-22}	0.96×10^{-22}
18	9.90×10^{-23}	9.92×10^{-23}	10.73×10^{-23}	0.81×10^{-23}
21	9.57×10^{-23}	9.58×10^{-23}	10.25×10^{-23}	0.67×10^{-23}
24	1.14×10^{-22}	1.15×10^{-22}	1.67×10^{-22}	0.52×10^{-23}
27	2.34×10^{-22}	2.35×10^{-22}	2.71×10^{-22}	0.36×10^{-22}

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