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Bremsstrahlung In Some Lead Compounds [$PBCl_2$, Pb [NO_3]$_2$, Pb [SO_4], Pb [CH_3COO]$_2$.$3H_2O$] at Lower Photon Energies [1-30 keV]

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Abstract—In the present studies, Z_{mod} for different lead compounds [$PBCl_2$, Pb[NO_3]$_2$, Pb[SO_4], Pb[CH_3COO]$_2$.$3H_2O$] has been calculated and using these values the bremsstrahlung cross sections were calculated at incident electron energies [10, 20 and 30 keV] in the lower photon energy region [1-30 keV]. The results have been calculated by using theories of elwert corrected [non relativistic] Bethe Heitler [1934], Modified Elwert factor [relativistic] Bethe Heitler theory for OB and Modified elwert factor [relativistic] Bethe Heitler theory that includes PB into OB given by Avdonina and Pratt [1999].

The effect of modified atomic no. and photon energy on bremsstrahlung cross sections at different energy regions [1-30 KeV] has been studied. Bremsstrahlung cross sections results from different theories are compared. It is observed that at lower photon energies PB factor is dominant and it decreases at higher photon energies.

Keywords: Ordinary bremsstrahlung, polarization bremsstrahlung, lead compounds.

I. INTRODUCTION

Ordinary Bremsstrahlung [OB] is the phenomenon of emission of radiations when fast moving electrons are deflected by static coulomb field of target nucleus. Polarization Bremsstrahlung [PB] is the process of emission of photons due to polarization of target atoms by the projected electrons. The total bremsstrahlung [BS] is the sum of intensities of OB and PB. The different theories are available for thin and thick targets in the ordinary bremsstrahlung [1-4].The limitation of these theories is that PB factor is not studied along with OB which is very important at lower photon energies.

Sommerfeld [5] developed the bremsstrahlung cross section formula by using the quantum theory for non relativistic electrons without taking effect of nuclear screening. Bethe Heitler [1] has given the expression for OB cross section $d\sigma(We,k,z)/dk$ for relativistic electrons using first order Born approximation without considering the effect of coulomb field on wave function of incident and scattered electrons. Elwert [2] gave the coulomb correction factor [Felwert] for bethe heitler cross section. Tseng and pratt has given quantum theory for bremsstrahlung for relativistic electrons using self screened consistent field wave function. Tseng and pratt [4], Koch and Motz [3] has given the reviews on the studies of OB.

Gray [6] and Chadwick [7] experimentally studied the OB spectra by using different beta emitters. Dhaliwal et al [8] studied the bremsstrahlung spectra in different metallic targets and concluded that the absorption factor of bremsstrahlung photons should not be a single valued function of target thickness and it should contain more no. of terms. Dhaliwal et al [9] compared the bremsstrahlung spectra in different metallic targets with different theoretical models and found the results in good agreement with the Avdonina and pratt[10] theory for high Z elements while Tseng and pratt theory was compatible with experimental results in high photon energy for medium and high Z elements.

Wendon and Nuroch [11] reported the presence of PB in Xe and rare earth element targets. Portillo and Quarles [12] performed experiments on gaseous targets to check the contribution of PB and reported the presence of PB over a large range of photon energy. T. Singh et al [13] reported the BS spectra in thick targets of Al, Sn, Ti and Pb using Tl204 beta source. In lower photon energy region [1-30 keV] the results were found be in good agreement with Modified elwert factor theory that includes PB by Avdonina and pratt [10] theory. They further concluded that in the lower photon energy region PB contribution is higher and can't be neglected. A. Singh [14] has reported the results in metallic targets in the energy region [1-100 keV] A good agreement of Avdonina and Pratt theory with the experimental results were observed at lower photon energy while results better match with Fmod Bethe Heitler theory in the higher photon energy region.

As compared to metals few bremsstrahlung studies are available in compounds and alloys. Subrahamanyam et al [15] reported yield constant for alloys using different beta emitters. Manjunatha and Rudraswamy [16] used langrange interpolation method to find BS cross section in NaI, SiLi and GeLi compounds using modified atomic numbers. Decrease in cross section was observed with increase in photon energy. Manjunatha and Rudraswamy [17] reported the bremsstrahlung yield in tissues, RNA and DNA using therapeutic nuclear source from the tabulated data by Lucien et al[18]. Manjunatha and Rudraswamy [19] reported the bremsstrahlung yield in PbCl2, CdO, Pb [NO3]2 and PbF2 compounds and compared the results with Tseng and pratt theory.

In all the studies of compounds the PB contribution has never been studied which is very important at lower photon energies.

2. Methodology:

BS cross sections of different compounds of lead has been studied using Elwert Corrected Bethe –Heitler theory, modified Elwert factor Bethe Heitler theory for OB and the modified Elwert factor Bethe Heitler theory that includes PB.

In the present work, Zmod has been calculated from the formula

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

Zmod- The modified effective atomic no. Of metallic compound

Wi, Zi, Ai- weight fraction, atomic weight and atomic no. of ith element in the compound.

The Bethe–Heitler OB cross section [σBH[We,K,Z] differential in photon energy k is given as,

$$\sigma_{BH}[W_{e,K,Z]} = \frac{P}{P_e}\left[\frac{4}{3} - 2w_e w \frac{P_e^2 + P^2}{P_e^2\, P^2} + \frac{E_e\, W}{P_e^3} + \frac{E_e W_e}{P^3} - \frac{E_e E}{P_e\, P} + L(A + B)\right]$$

We, W=initial and final total energy of electron

Pe, P=initial and final momentum of electron

The multiplicative coulomb correction factor [Felwert] for Bethe-Heitler OB cross section is given as

Felw=[W/P[1-exp[-2παZ[2παZWe/Pe]]]/[We/Pe[1-exp[-2παZW/P]]]

Modified elewert factor is given as Fmod=[[Pi [1-exp[-2πZ/αPi]]/[Pf [1-exp[-2πZ/αPf]]

Corrected modified OB cross section σ_{cor}[We,k,Z] is given by

σ_{cor}[we,k,z] = C[Ti, Z] F_{mod} σBH[we,K,Z]

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

σ[We,K,Z] = σB[k] - $\sqrt{3}/\pi \ln q_+/q_-$ + σ_{cor} [we,K,Z]

The computer Fortran programs were written to calculate the theoretical cross sections for Elwert Corrected Bethe –Heitler theory, modified Elwert factor Bethe Heitler theory for OB and the modified Elwert factor Bethe Heitler theory that includes PB.

3. Results and Discussion:

Theoretical values of cross sections of lead compounds[Pb[CH3COO]2.2H2O,Pb[NO3]2,Pb[SO4], PbCl2 has been evaluated at different energies of electron [1-30 keV] in different photon energy regions using the theories of Bethe Heitler [1], Bethe Heitler corrected theory[2] and Avdonina and Pratt theory[10]. Corresponding graphs have been plotted between photon energy [keV] and cross sections [cm^2/m_0c^2]. From these results it can be concluded that

1. The cross section decreases as the energy of photon increases also there is decrease in bremsstrahlung cross section with increase in energy of incident electron.
2. With the increase in modified atomic no. of the compounds there is an increase in bremsstrahlung cross section.
3. It has been observed that at lower photo energies the bremsstrahlung cross section is comparatively larger. This is due to PB contribution at lower photon energy is large. This contribution has never been studied in compounds.
4. There is continuous decrease of Pb cross section with increase in energy of photon. From the below theoretical results [table 1-4] and graphs [1-4] it can be concluded that there is need to study bremsstrahlung theoretically and practically in compounds especially at lower photon energies to verify the accuracy of theoretical models.

Table 1. Bremsstrahlung cross section table for Pb [$CH_3COO]_2.2H_2O$ [Lead Acetate] compound at 10 keV-30 keV] incident electron energy In the range of 1-10 keV,1-20 keV,1-30 keV photon energy [Zmod= 42.11]

T_E= 10 keV				
K	Σ_{EBH}	ΣCOR	ΣCOR+PB	% DEVIATION ={[[ΣCOR+PB]-ΣCOR]/ ΣCOR}*100
1	2.81×10^{-19}	2.95×10^{-19}	7.45×10^{-19}	153
2	1.19×10^{-19}	1.25×10^{-19}	2.61×10^{-19}	109
3	7.22×10^{-20}	7.61×10^{-20}	13.82×10^{-20}	82
4	5.12×10^{-20}	5.40×10^{-20}	8.68×10^{-20}	61

5	4.02×10^{-20}	4.25×10^{-20}	6.15×10^{-20}	45
6	3.46×10^{-20}	3.66×10^{-20}	4.82×10^{-20}	32
7	3.34×10^{-20}	3.54×10^{-20}	4.28×10^{-20}	21
8	3.98×10^{-20}	4.23×10^{-20}	4.73×10^{-20}	12
9	8.07×10^{-21}	8.60×10^{-21}	9.03×10^{-21}	5
T_E= 20 keV				
2	7.17×10^{-20}	7.53×10^{-20}	18.99×10^{-20}	152
4	3.02×10^{-20}	3.19×10^{-20}	6.64×10^{-20}	108
6	1.82×10^{-20}	1.93×10^{-20}	3.49×10^{-20}	81
8	1.29×10^{-20}	1.37×10^{-20}	2.20×10^{-20}	61
10	1.01×10^{-20}	1.07×10^{-20}	1.55×10^{-20}	45
12	8.62×10^{-21}	9.23×10^{-21}	12.14×10^{-21}	32
14	8.30×10^{-21}	8.92×10^{-21}	10.78×10^{-21}	21
16	9.88×10^{-21}	1.07×10^{-21}	1.19×10^{-21}	11
18	2.01×10^{-20}	2.18×10^{-20}	2.29×10^{-20}	5
T_E= 30 keV				
3	3.24×10^{-20}	3.41×10^{-20}	8.61×10^{-20}	152
6	1.36×10^{-20}	1.44×10^{-20}	3.00×10^{-20}	108
9	8.16×10^{-21}	8.70×10^{-21}	15.7×10^{-21}	80
12	5.74×10^{-21}	6.15×10^{-21}	9.87×10^{-21}	60
15	4.47×10^{-21}	4.82×10^{-21}	6.96×10^{-21}	44
18	3.81×10^{-21}	4.14×10^{-21}	5.44×10^{-21}	31
21	3.66×10^{-21}	4.00×10^{-21}	4.82×10^{-21}	21
24	4.36×10^{-21}	4.78×10^{-21}	5.35×10^{-21}	12
27	8.87×10^{-21}	9.79×10^{-21}	10.28×10^{-21}	5

Graph1.(a,b,c)Variation of bremsstrahlung cross section with photon energy [1-10keV], [1-20keV], [1-30keV], at 10keV,20keV,30 keV electron energy for lead acetate [Zmod=42.11]

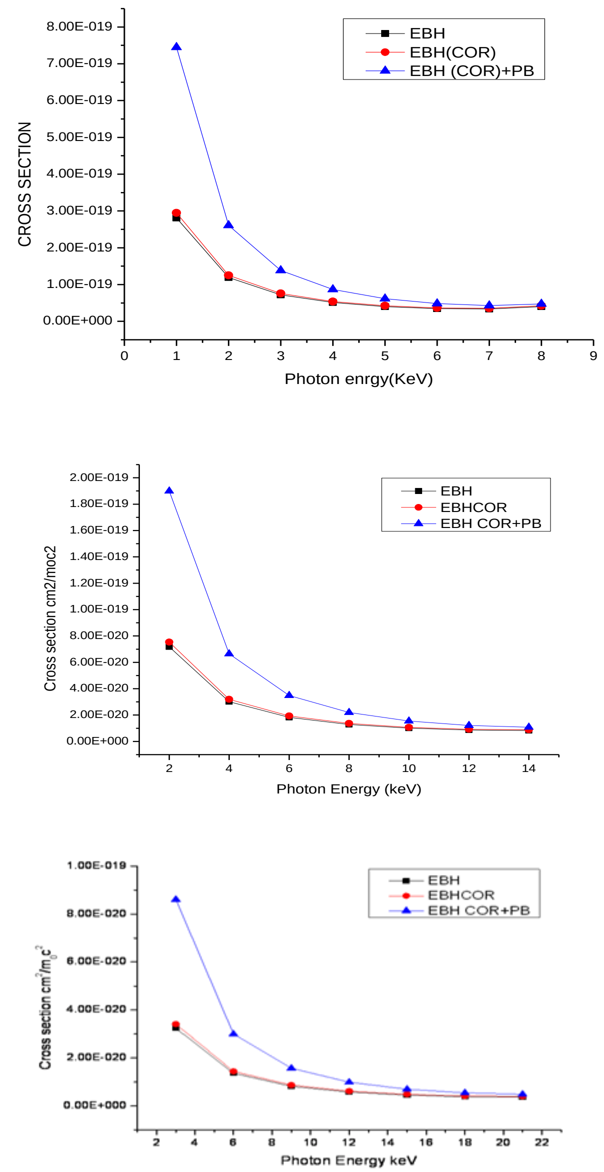
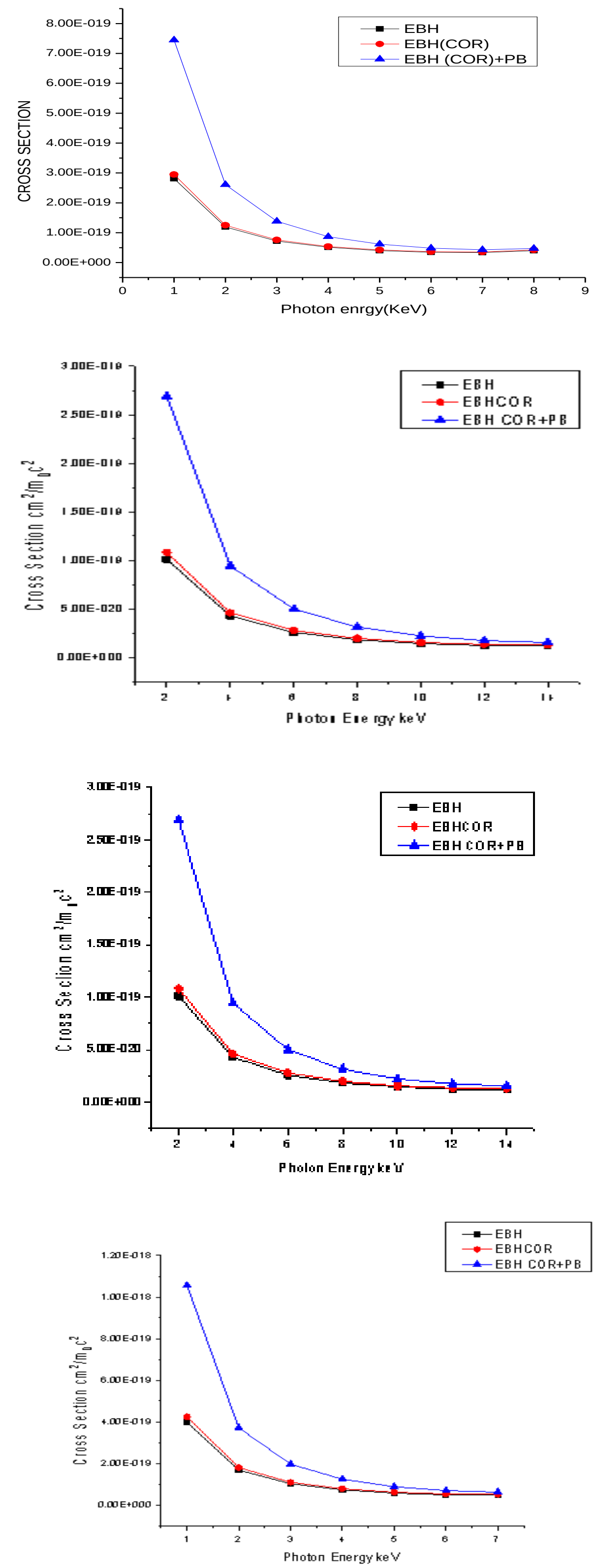


Table 2.Bremsstrahlung cross section table for Pb[NO3]2 Lead Nitrate compound at 10 KeV-30KeV incident electron energy In the range of 1-10 keV,1-20 keV,1-30 keV photon energy Zmod= 50.04

T_E= 10KEV				
K	ΣEBH	ΣCOR	ΣCOR+PB	% DEVIATION
1	3.97×10^{-19}	4.24×10^{-19}	10.56×10^{-19}	149
2	1.68×10^{-19}	1.80×10^{-19}	3.71×10^{-19}	106

3	1.02×10^{-19}	1.09×10^{-19}	1.96×10^{-19}	80
4	7.23×10^{-20}	7.77×10^{-20}	12.36×10^{-20}	59
5	5.68×10^{-20}	6.11×10^{-20}	8.77×10^{-20}	44
6	4.88×10^{-20}	5.26×10^{-20}	6.88×10^{-20}	31
7	4.71×10^{-20}	5.09×10^{-20}	6.12×10^{-20}	20
8	5.61×10^{-20}	6.08×10^{-20}	6.78×10^{-20}	12
9	1.14×10^{-19}	1.24×10^{-19}	1.29×10^{-19}	4
T_E= 20KEV				
2	1.01×10^{-19}	1.08×10^{-19}	2.69×10^{-19}	149
4	4.27×10^{-20}	4.58×10^{-20}	9.42×10^{-20}	106
6	2.57×10^{-20}	2.77×10^{-20}	4.96×10^{-20}	79
8	1.82×10^{-20}	1.96×10^{-20}	3.13×10^{-20}	60
10	1.42×10^{-20}	1.54×10^{-20}	2.21×10^{-20}	44
12	1.22×10^{-20}	1.33×10^{-20}	1.73×10^{-20}	30
14	1.17×10^{-20}	1.28×10^{-20}	1.54×10^{-20}	20
16	1.40×10^{-20}	1.53×10^{-20}	1.71×10^{-21}	12
18	2.84×10^{-20}	3.13×10^{-20}	3.28×10^{-20}	5
T_E= 30KEV				
3	4.58×10^{-20}	4.90×10^{-20}	12.20×10^{-20}	149
6	1.92×10^{-20}	2.07×10^{-20}	4.26×10^{-20}	106
9	1.15×10^{-20}	1.25×10^{-20}	2.23×10^{-20}	78
12	8.11×10^{-21}	8.84×10^{-21}	14.06×10^{-21}	59
15	6.32×10^{-21}	6.93×10^{-21}	9.92×10^{-21}	43
18	5.40×10^{-21}	5.95×10^{-21}	7.76×10^{-21}	30
21	5.18×10^{-21}	5.75×10^{-21}	6.89×10^{-21}	20
24	6.17×10^{-21}	6.88×10^{-21}	7.66×10^{-21}	11
27	0.12×10^{-21}	0.14×10^{-21}	0.15×10^{-21}	7

Graph2.(a,b,c)Variation of bremsstrahlung cross section with photon energy [1-10keV], [1-20keV], [1-30keV], at 10keV,20keV,30 keV electron energy for lead nitrate [Zmod=50.04]

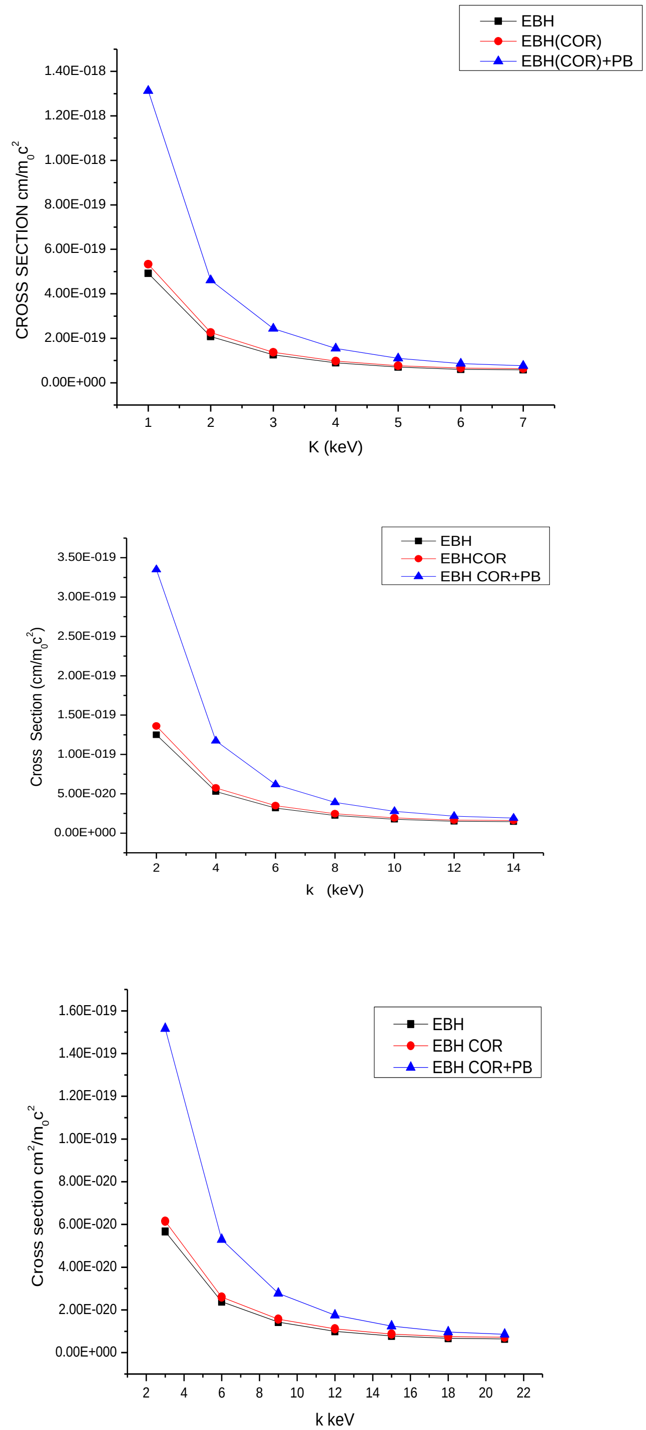


International Journal of Pure and Applied Physics. ISSN 0973-1776 Volume 13, Number 1 (2017), pp. 215-221

Table 3.Bremsstrahlung cross section table for Pb[SO]4 Lead Sulphate compound at 10 KeV-30KeV incident electron energy In the range of 1-10 keV,1-20 keV,1-30 keV photon energy [Zmod= 55.66]

T_E= 10 keV				
K	ΣEBH	ΣCOR	ΣCOR+PB	% DEVIATION
1	4.92×10^{-19}	5.33×10^{-19}	13.13×10^{-19}	146
2	2.08×10^{-19}	2.26×10^{-19}	4.61×10^{-19}	104
3	1.26×10^{-19}	1.37×10^{-19}	2.44×10^{-19}	78
4	8.95×10^{-20}	9.76×10^{-20}	15.41×10^{-20}	58
5	7.03×10^{-20}	7.67×10^{-20}	10.94×10^{-20}	43
6	6.04×10^{-20}	6.61×10^{-20}	8.59×10^{-20}	30
7	5.83×10^{-20}	6.39×10^{-20}	7.65×10^{-20}	20
8	6.95×10^{-20}	7.64×10^{-20}	8.49×10^{-20}	11
9	1.41×10^{-19}	1.55×10^{-19}	1.62×10^{-19}	5
T_E= 20 keV				
2	1.25×10^{-19}	1.36×10^{-19}	3.35×10^{-19}	146
4	5.28×10^{-20}	5.75×10^{-20}	11.73×10^{-20}	104
6	3.18×10^{-20}	3.48×10^{-20}	6.18×10^{-20}	78
8	2.25×10^{-20}	2.47×10^{-20}	3.90×10^{-20}	58
10	1.76×10^{-20}	1.94×10^{-20}	2.76×10^{-20}	42
12	1.51×10^{-20}	1.66×10^{-20}	2.16×10^{-20}	30
14	1.45×10^{-20}	1.61×10^{-20}	1.92×10^{-20}	19
16	1.73×10^{-20}	1.92×10^{-20}	2.14×10^{-20}	11
18	3.51×10^{-20}	3.93×10^{-20}	4.11×10^{-20}	5
T_E= 30 keV				
3	5.67×10^{-20}	6.15×10^{-20}	15.17×10^{-20}	147
6	2.38×10^{-20}	2.60×10^{-20}	5.30×10^{-20}	104
9	1.43×10^{-20}	1.57×10^{-20}	2.78×10^{-20}	77
12	1.00×10^{-20}	1.11×10^{-20}	1.75×10^{-20}	58
15	7.82×10^{-21}	8.69×10^{-21}	12.38×10^{-21}	42
18	6.68×10^{-21}	7.46×10^{-21}	9.69×10^{-21}	30
21	6.42×10^{-21}	7.21×10^{-21}	8.62×10^{-21}	20
24	7.63×10^{-21}	8.63×10^{-21}	9.59×10^{-21}	11
27	1.55×10^{-20}	1.77×10^{-20}	1.85×10^{-20}	5

Graph3. a,b,c Variation of bremsstrahlung cross section with photon energy for lead Sulphate at10 keV,20 keV and 30 keV [Zmod=42.11]

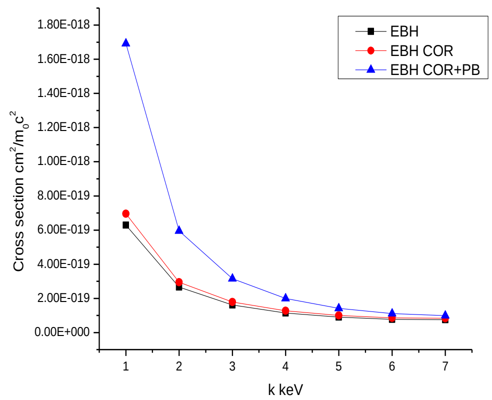


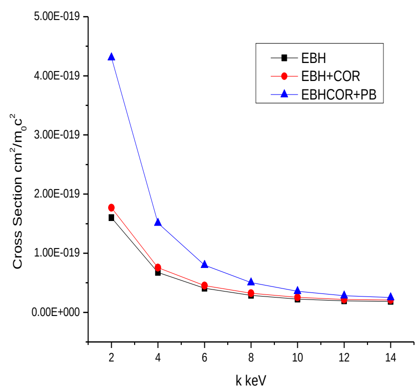
International Journal of Pure and Applied Physics. ISSN 0973-1776 Volume 13, Number 1 (2017), pp. 215-221

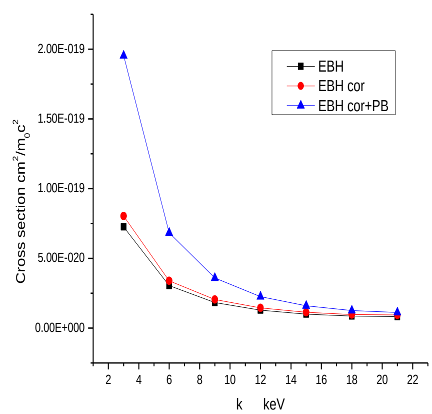
Table 4.Bremsstrahlung cross section table for PbCl2 Lead Chloride compound at 10 KeV-30KeV incident electron energy In the range of 1-10 keV,1-20 keV,1-30 keV photon energy Zmod= 62.95

T_E= 10KEV				
K	ΣEBH	ΣCOR	ΣCOR+PB	% DEVIATION
1	6.29×10^{-19}	6.96×10^{-19}	16.92×10^{-19}	143
2	2.66×10^{-19}	2.95×10^{-19}	5.95×10^{-19}	102
3	1.61×10^{-19}	1.79×10^{-19}	3.15×10^{-19}	76
4	1.14×10^{-19}	1.27×10^{-19}	1.99×10^{-19}	57
5	8.98×10^{-20}	10.02×10^{-20}	14.20×10^{-20}	42
6	7.72×10^{-20}	8.63×10^{-20}	11.14×10^{-20}	29
7	7.46×10^{-20}	8.35×10^{-20}	9.94×10^{-20}	19
8	8.89×10^{-20}	9.97×10^{-20}	11.05×10^{-20}	11
9	1.80×10^{-19}	2.03×10^{-19}	2.11×10^{-19}	4
T_E= 20KEV				
2	1.60×10^{-19}	1.77×10^{-19}	4.31×10^{-19}	144
4	6.75×10^{-20}	7.57×10^{-20}	15.12×10^{-20}	100
6	4.07×10^{-20}	4.54×10^{-20}	7.98×10^{-20}	76
8	2.87×10^{-20}	3.22×10^{-20}	5.04×10^{-20}	57
10	2.25×10^{-20}	2.53×10^{-20}	3.57×10^{-20}	41
12	1.93×10^{-20}	2.17×10^{-20}	2.81×10^{-20}	29
14	1.85×10^{-20}	2.10×10^{-20}	2.50×10^{-20}	19
16	2.21×10^{-20}	2.51×10^{-20}	2.78×10^{-20}	11
18	4.49×10^{-20}	5.12×10^{-20}	5.35×10^{-20}	4
T_E= 30KEV				
3	7.25×10^{-20}	8.03×10^{-20}	19.54×10^{-20}	143
6	3.04×10^{-20}	3.39×10^{-20}	6.83×10^{-20}	101
9	1.83×10^{-20}	2.05×10^{-20}	3.59×10^{-20}	75
12	1.28×10^{-20}	1.45×10^{-20}	2.26×10^{-20}	56
15	1.00×10^{-20}	1.13×10^{-20}	1.60×10^{-20}	42
18	8.54×10^{-21}	9.74×10^{-21}	12.57×10^{-21}	29
21	8.21×10^{-21}	9.42×10^{-21}	11.19×10^{-21}	19
24	9.76×10^{-21}	11.27×10^{-21}	12.47×10^{-21}	11
27	0.20×10^{-21}	0.23×10^{-21}	0.24×10^{-21}	4

Graph 4. Variation of bremsstrahlung cross section with photon energy for lead Chloride at 10 keV,20 keV,30 keV [Zmod=42.11]







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