Mass Attenuation Coefficients Of Un-Doped Borate Silica Glass System At 0.662 And 1.25 Mev Gamma Energies

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Abstract

The total mass attenuation coefficients, partial interactions and Z_{eff} of glass system un-doped composition (90-x)ZnO-xB_2O_3-10SiO_2, where x= 30, 35, 40, 45, 50 mol% at photon energies 0.662 and 1.25 MeV have been calculated on the basis of mixture rule using Win XCom software. Results specified that the total mass attenuation coefficients showed decreased with increasing ZnO concentrations, because of a decrease in Compton scattering probability, which gave a dominant contribution to the total mass attenuation coefficients for the studied glass samples at 0.662 and 1.25 MeV energies. Also, the photoelectric absorption and coherent scattering show an increase with increasing ZnO concentrations at both energies. For comparison, the total mass attenuation coefficients of the glass system had higher values at energy 0.662 MeV than that at 1.25 MeV. Effective atomic number (Z_{eff}) was found, it was obviously to increase linearly as ZnO concentrations increase. Therefore, it is recommended to use low ZnO content in borate silica glass system which makes it suitable for radiation detection purposes for the environment and industry.

Keywords:Mass Attenuation Coefficients, Borate Silica Glass System, Gamma Energies

معاملات التوهين الكتلي لنظام زجاج السيليكا غير المنشط عند 0.662 و 1.25 ميكا إلكترون فولت من طاقات الاشعاع كاما

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الخلاصة:

إجمالي معاملات التوهين الكتلي والتفاعلات الجزئية و عدد ذري فعال Zeff لمركب غير منشط لنظام الزجاج ZnO (x-90) - 10SiO- xB_2O_3 ، حيث x = 30 ، 35 ، 40 ، 45 ، 50مول٪ عند طاقات الفوتون 0.662 و 1.25 إلكترون فولت لها تم حسابها على أساس قاعدة الخلط باستخدام برنامج Win XCom.أوضحت النتائج أن معاملات التوهين الكتلي الكلية أظهرت انخفاضًا مع زيادة تراكيز ZnO بسبب انخفاض احتمالية تشتت كومبتون ، مما أعطى مساهمة سائدة في معاملات التوهين الكتلي الكلي لعينات الزجاج المدروسة عند طاقتي 0.662 و 1.25 إلكترون فولت .أيضًا ، يظهر الامتصاص الكهروضوئي والتشتت المتماسك زيادة مع زيادة تركيزات ZnO في كلا الطاقتين .للمقارنة ، كان لمعاملات التوهين الكتلي الكلي للنظام الزجاجي قيم أعلى عند الطاقة 0.662 ميكا إلكترون فولت عن تلك عند 1.25 ميكا إلكترون فولت .تم العثور على عدد ذري فعال (Zeff) ، ومن الواضح أنه يزداد خطيًا مع زيادة تركيزات ZnO. لذلك ، يوصى باستخدام محتوى منخفض من ZnO في نظام زجاج بورات السيليكا مما يجعله مناسبًا لأغراض الكشف عن الإشعاع للبيئة والصناعة.

الكلمات المفتاحية: معاملات التوهين الكتلي ، نظام زجاج بورات السيليكا ، طاقات كاما.

1. Introduction

The mass attenuation coefficient is a measure of the probability of the interaction that occurs between incident photons and the matter of the unit mass per unit area. The knowledge of the mass attenuation coefficients of X and λ-ray in biological and other important materials is of significant interest for industrial, biological, agricultural, and medical applications [1, 2]**.** Mass attenuation coefficient is a measurement of how strongly a chemical specie or substance absorbs or scatters radiation at a given wavelength, per unit mass [3]. The energy absorption in a given medium can be calculated by means of well established formulae if convinced constants such as effective atomic number and electron density of the medium are known[4]. The information of parameters such as mass attenuation coefficient (μ_m), linear attenuation coefficient (μ_l), total atomic cross-section (σt), electronic cross-section (σe), effective atomic number (Z_{eff}), electron density (N_{eff}), mean free-path (λ) acting an important role in understanding the physical properties of compound materials. [3]. To found effective atomic numbers (Z,~) various attempts have been made for partial and total gamma ray interactions in alloys and compounds, some empirically deduced formulas have been reported in the literature but their validity is incomplete to the experimental conditions used in that particular work [5]. The response of a thermoluminescent material to γ- ray detection depends on the atomic number of its constituents; then it is important to know first the effective atomic number of such material, Z_{eff}, for obtaining its expected TL response at different energies[6]. To calculate the total mass attenuation coefficient, the software WinXCom was utilized [7]. Berger and Hubbel developed the theoretical tables and computer program (XCOM) for calculating attenuation coefficients for elements, compounds and mixtures for photon energies from 1keV to 100GeV. This program was transformed to the Windows platform by Gerward et .al[8], and the Windows version is being called WinXcom[3]. WinXCom is now become a familiar software to calculate interaction cross-sections of gamma rays with any elements, compounds or mixture in the energy range between 1 keV to 100 GeV. By using WinXCom software, it is possible to calculate and compare mass attenuation coefficients between theoretical and experimental results**[9]**.

2. Calculation Method

The glass material having un-doped composition (90-x)ZnO-xB_2O_3-10SiO_2, where x= 30, 35, 40, 45, 50 mol% were investigated in our previous report [10, 11] and used to study in this work. The total mass attenuation coefficient of the studied glasses for photon energies 0.662 MeV and 1.25 MeV were calculated theoretically by using Win XCom software based on the mixture rule as follow:

$$\left(\frac{\mu}{\rho}\right) = \sum_i^n w_i \left(\frac{\mu}{\rho}\right)_i \qquad ....(1)$$

Where $\left(\frac{\mu}{\rho}\right) i$ is the mass attenuation coefficient for individual element and w_i is the weight fraction of each element, boron (B), oxygen (O), zinc (Zn), silica (Si). The effective atomic number can be obtained according to Eq.2 [12]

$$Z_{eff} = \sqrt[b]{(a_1 x Z_1^b + a_2 x Z_2^b + \cdots)} \qquad .... (2)$$

$$a_i = \frac{n_i(Z_i)}{\sum_i n_i(Z_i)}, \quad n_i = N_A Z_i$$

where a_1, a_2 ,... are the fractional contents of electrons that are belong to different elements of atomic number, Z_1 , Z_2 , … . in the composite system, n_i is the number of electrons in one mole, belonging to each element Zi and N_A is the Avogadro's number.

The range of b are in the range from 2.94 to 3.5 [12].

3. Results and Discussions

In this study, the un-doped composition (90-x) ZnO-xB_2O_3-$10SiO_2$, where x= 30, 35, 40, 45, 50 mol% was converted to weight fraction and given in table (1).

Table 1: The raw materials for undoped glasses system.

Batches Composition (mol%)			
Samples	*ZnO*	*B_2O_3*	*SiO_2*
S1	*60*	*30*	*10*
S2	*55*	*35*	*10*
S3	*50*	*40*	*10*
S4	*45*	*45*	*10*
S5	*40*	*50*	*10*

The total mass attenuation coefficients, of the studied glass systems were calculated at two

photon energies 0.662 (^{137}Cs-source) and 1.25 MeV (average energy of ^{60}Co-source) using the WinXCom software on the basis of mixture [7, 13].

Photoelectric mass absorption cross section (μ_m^{ph})

Based on our calculations, it was found that the photoelectric cross section (μ_m^{ph}) of the studied glass system at 0.662 and 1.25 MeV an increase with increasing the ZnO concentrations as shown in Fig. 1. It is very clear from Fig. 1 that the values of (μ_m^{ph}) at low photon energy (0.662 MeV) are higher than those at high energy (1.25 MeV). In addition, the slope of the straight line between (μ_m^{ph}) and ZnO concentrations at 0.662

MeV is higher than that at 1.25 MeV. Therefore, the effect of increasing ZnO concentrations showed an increase in the (μ_m^{ph}) values of the studied glass systems at both energies.

Compton scattering (μ_m^{cs})

Compton scattering mass attenuation coefficients ((μ_m^{cs}) of the studied glass system were calculated using WinXcom software. The result is given in Fig. 2. The (μ_m^{cs}) values show a slight decrease with increasing ZnO concentration. Also, values of (μ_m^{cs}) at 0.662 MeV are higher than those at 1.25 MeV. Therefore, both (μ_m^{ph}) and (μ_m^{cs}) values are more effective at low energy value, i.e at 0.662 MeV.

Coherent Scattering (μ_m^{ch})

The Coherent scattering mass attenuation coefficients (μ_m^{ch}) of the studied glass system were also calculated and the result is represented in Fig. 3. The rate of increase in (μ_m^{ch}) is obvious at the energy of 0.662MeV higher than those at 1.25 MeV with increasing ZnO concentration.

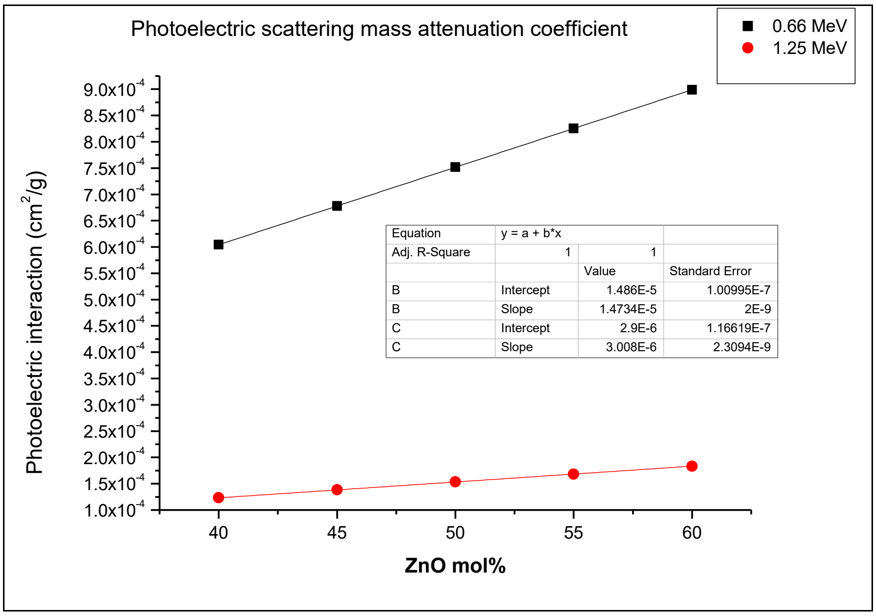


Fig. 1 photoelectric mass absorption coefficient of undoped composition (90-x)ZnO-xB$_2$O$_3$-10SiO$_2$

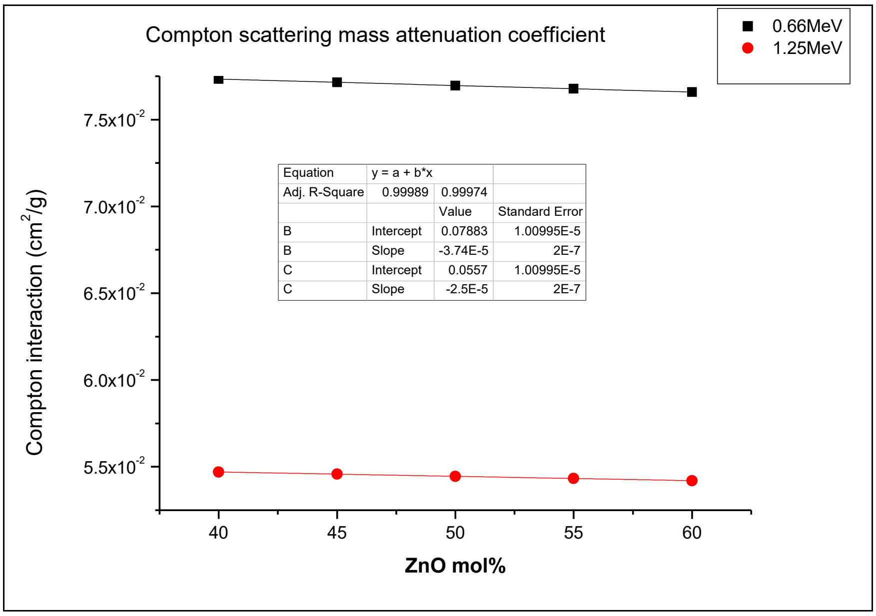


Fig. 2 The Compton scattering interaction of (90-x) ZnO-xB2O3-10SiO2 with various of ZnO mol%

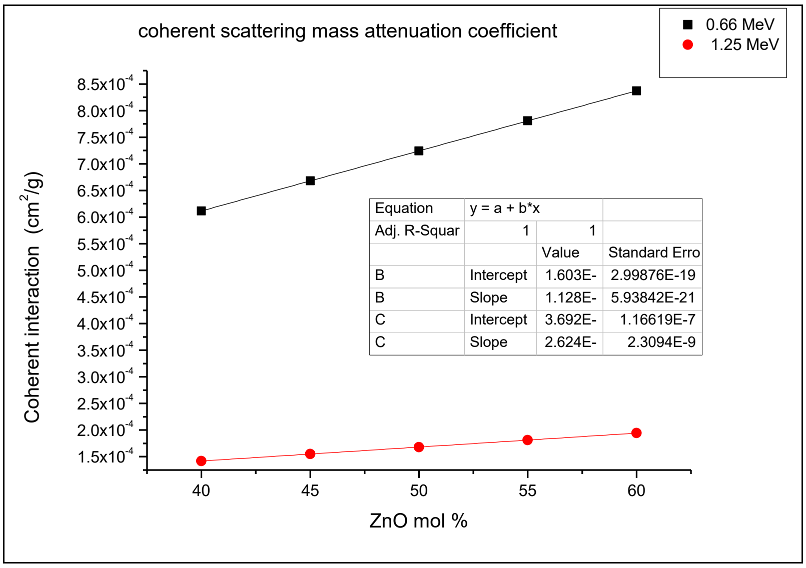


Fig. 3: The coherent scattering mass attenuation coefficient of (90-x)ZnO-xB2O3-10SiO2 with various of ZnO mol%.

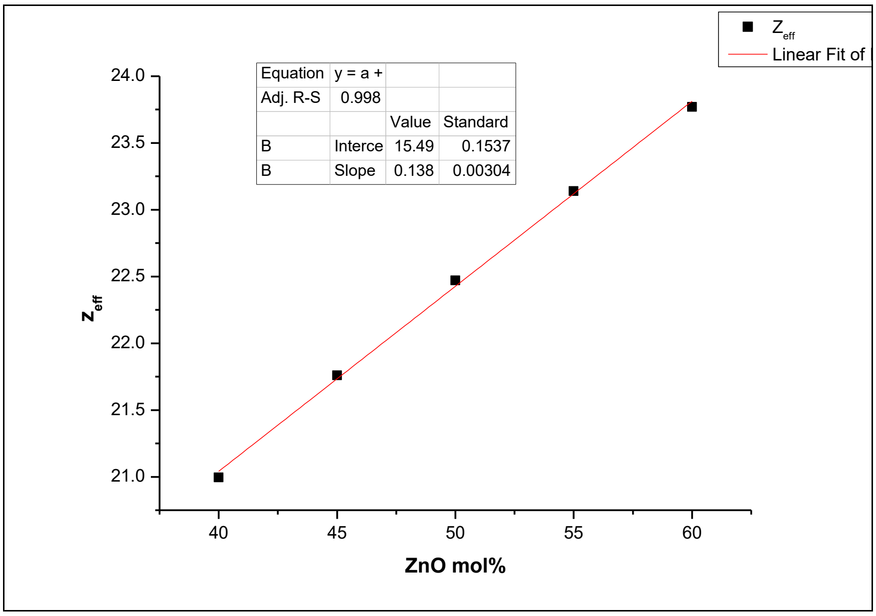
From the above calculations of photoelectric, Compton and coherent interaction, the total mass absorption coefficient were calculated and illustrated in Table 2, we observe that the total absorption coefficient closes to the Compton interaction values. To confirm the obtained values of the attenuation coefficient of the studied glass, the effective atomic number (Z_{eff}) should be calculated and compared the obtained data by the attenuation coefficient of the element with Z has the same or near Z_{eff} .

Zeff –calculation

Z_{eff} was calculated for the studied glass samples and given in Table 3(A, B, C, D and E) using Eq. (2). Column 1 gives the ZnO concentration, element under study is given under column 2, the atomic weight, *A* and atomic number *Z* are given under columns 3 and 4, respectively. Weight fraction, *w*, and the total number of electrons per gm, $N_A Z w / A$ are displayed under columns 5 and 8 respectively. The fraction number of electrons due to each element in the composition is then calculated and given under column 9 and denoted by *a*. The values of $a\ Z^b$ were then calculated and given under the last two columns where *b* takes the values 2.94 and 3.5. Finally, values of Z_{eff} were calculated and given in the last row of each glass composition. The variation of the mean values of Zeff of the present glass system with ZnO is given in Fig. 4. It is clear that (see Fig. 4), Zeff increases with increasing the ZnO concentration and their values range from 23.335 to 28.862. This variation is represented by an excellent linearity form with R^2=0.998.

Table 2. Total absorption coefficient values of the studied glass system.

Sample ZnO%	Energy(MeV)	Coherent	Compton (cm2/g)	Photoelectric	Sum
60	0.662	8.37E-04	7.66E-02	8.99E-04	7.83E-02
	1.25	1.94E-04	5.42E-02	1.83E-04	5.46E-02
55	0.662	7.81E-04	7.68E-02	8.25E-04	7.84E-02
	1.25	1.81E-04	5.43E-02	1.68E-04	5.47E-02
50	0.662	7.24E-04	7.70E-02	7.52E-04	7.84E-02
	1.25	1.68E-04	5.45E-02	1.53E-04	5.48E-02
45	0.662	6.68E-04	7.72E-02	6.78E-04	7.85E-02
	1.25	1.55E-04	5.46E-02	1.38E-04	5.49E-02
40	0.662	6.12E-04	7.73E-02	6.04E-04	7.86E-02
	1.25	1.42E-04	5.47E-02	1.23E-04	5.50E-02



Fig(4) The effective atomic number of (90-x)ZnO-xB2O3-10SiO2 with various of ZnO mol%.

Table 3A, Zeff calculation for our studied glass samples (90-x)ZnO-xB_2O_3-10SiO_2 when ZnO =60

Sample	Element	A	Z	Weight Fraction(W_i)	NA Z	W/A	NAZ(W/A)	a	$a*Z^{2.94}$	$a*Z^{3.5}$
ZnO (60)	B	10.811	5	0.093171	3.001E+24	8.62E-03	2.59E+22	0.090412	10.261187	25.270905
	O	15.999	8	0.378032	4.8016E+24	2.36E-02	1.13E+23	0.396613	179.246697	574.356517
	Si	28.08554	14	0.046744	8.4028E+24	1.66E-03	1.40E+22	0.048889	114.506052	501.949634
	Zn	65.382	30	0.482053	1.8006E+25	7.37E-03	1.33E+23	0.464086	10217.278203	68631.441621
sumi				**1.0000**			**2.86E+23**		**10521.292139**	**69733.018678**
$\mathbf{Z_{eff}}$									**23.33730528**	**24.20134828**

Table 3B, Zeff calculation for our studied glass samples (90-x)ZnO-xB_2O_3-10SiO_2 when ZnO =55

Sample	Element	A	Z	Weight Fraction(W)	NA Z	W/A	NAZ(W/A)	a	$a*Z^{2.94}$	$a*Z^{3.5}$
ZnO (55)	B	10.811	5	0.1087	3.001E+24	1.01E-02	3.02E+22	0.105244	11.944569	29.416683
	O	15.999	8	0.402675	4.8016E+24	2.52E-02	1.21E+23	0.421519	190.502805	610.424235
	Si	28.08554	14	0.046744	8.4028E+24	1.66E-03	1.40E+22	0.048779	114.249038	500.822985
	Zn	65.382	30	0.441882	1.8006E+25	6.76E-03	1.22E+23	0.424458	9344.818060	62770.957430
sumi				**1.0000**			**2.87E+23**		**9661.514472**	**63911.621332**
$\mathbf{Z_{eff}}$									**22.67031497**	**23.60602213**

Table 3C, Zeff calculation for our studied glass samples (90-x)ZnO-xB_2O_3-10SiO_2 when ZnO =50

Sample	Element	A	Z	Weight Fraction(W)	NA Z	W/A	NAZ(W/A)	a	$a*Z^{2.94}$	$a*Z^{3.5}$

ZnO (50)	*B*	*10.811*	*5*	*0.124228*	*3.001E+24*	*1.15E-02*	*3.45E+22*	*0.120010*	*13.620329*	*33.543688*
	O	*15.999*	*8*	*0.427317*	*4.8016E+24*	*2.67E-02*	*1.28E+23*	*0.446313*	*201.708430*	*646.330190*
	Si	*28.08554*	*14*	*0.046744*	*8.4028E+24*	*1.66E-03*	*1.40E+22*	*0.048670*	*113.993404*	*499.702387*
	Zn	*65.382*	*30*	*0.401711*	*1.8006E+25*	*6.14E-03*	*1.11E+23*	*0.385007*	*8476.282741*	*56936.837046*
sumi				***1.0000***			***2.87E+23***		***8805.604905***	***58116.413311***
Z_{eff}									***21.96619468***	***22.97355633***

Table 3D, Zeff calculation for our studied glass samples (90-x)ZnO-xB_2O_3-10SiO_2 when ZnO =45

Sample	Element	A	Z	Weight Fraction(W)	NA Z	W/A	NAZ(W/A)	a	$a*Z^{2.94}$	$a*Z^{3.5}$
ZnO (45)	B	10.811	5	0.139757	3.001E+24	1.29E-02	3.88E+22	0.134710	15.288686	37.652461
	O	15.999	8	0.45196	4.8016E+24	2.82E-02	1.36E+23	0.470997	212.864066	682.075965
	Si	28.08554	14	0.046744	8.4028E+24	1.66E-03	1.40E+22	0.048561	113.738684	498.585792
	Zn	65.382	30	0.36154	1.8006E+25	5.53E-03	9.96E+22	0.345732	7611.610195	51128.663655
sumi				**1.0000**			**2.88E+23**		**7953.501630**	**52346.977872**
Z_{eff}									**21.21878613**	**22.2974268**

Table 3E, Zeff calculation for our studied glass samples (90-x)ZnO-xB_2O_3-10SiO_2 when ZnO =40

Sample	Element	A	Z	Weight Fraction(W)	NA Z	W/A	NAZ(W/A)	a	$a*Z^{2.94}$	$a*Z^{3.5}$
ZnO (40)	B	10.811	5	0.155285	3.001E+24	1.44E-02	4.31E+22	0.149343	16.949528	41.742727
	O	15.999	8	0.476602	4.8016E+24	2.98E-02	1.43E+23	0.495570	223.969936	717.662278
	Si	28.08554	14	0.046744	8.4028E+24	1.66E-03	1.40E+22	0.048453	113.485326	497.475172

	Zn	65.382	30	0.321369	1.8006E+25	4.92E-03	8.85E+22	0.306633	6750.806800	45346.480108
sum i				**1.0000**			**2.89E+23**		**7105.211591**	**46603.360284**
Z_{eff}									**20.42021025**	**21.5691 7305**

Conclusion

The total mass attenuation coefficients and partial interactions at photon energies 0.662and 1.25 MeV of glass system (90-x) ZnO-xB_2O_3-10SiO_2, where x= 30, 35, 40, 45, 50 mol% have been investigated using the Win X Com software. Results showed that total mass attenuation coefficients increased with increasing ZnO concentrations, due to a decrease in Compton scattering of glass samples which contribute dominantly to the total interaction. Although, the coherent scattering showed an increase with increasing ZnO concentrations but it has lower values than Compton scattering. The photoelectric interaction also increases in these glass samples. In addition, the Zeff values of our studied glasses showed an increase with increasing ZnO concentrations and found to have values from 23.335 to 28.862. Results recommend this glass system as a TL γ-dosimeter especially at low ZnO content.

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