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GAMMA RAY ATTENUATION STUDIES OF BINARY BORATE GLASSES CONTAINING Li_2O & Bi_2O_3

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ABSTRACT

Glasses having oxides of bismuth and lithium are synthesized by using melting & quenching technique. The various physical properties like density, molar volume& mass attenuation-coefficients are analyzed. Mass attenuation –coefficients & half value layer are compared with concretes for the estimation of better shielding material.

Introduction:

The use of materials displaying radioactivity is increasing day by day in various sectors. Power generation from radioactive materials is the most common use which is used in various nuclear reactors. Further the radiations emitted from these sources are very harmful to living organisms. The gamma radiations emitted from the radioactive materials have short wavelength and associated

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with a large value of energy. These gamma radiations can penetrate a large distance in the environment and can make harmful effects to the environment as well as to the species. To prevent these radiations to escape in the environment a very high thick wall of concrete is required as shielding material. As concrete is opaque so search of new materials is required which can be alternate to concrete and also transparent. From recent studies many researchers have found that borate glasses can be the promising candidates as the shielding materials.

Borate based glasses have been analyzed by many researchers for radiation shielding materials [1-4]

Synthesis of the glasses and theoretical calculations:

2.1 Synthesis of glass, X-ray diffraction & density measure

Synthesized glass materials of the various chemical composition are listed in table number 1 were synthesized with the help of melting & quenching technique. AR (analytical reagent) grade chemicals had been utilized for synthesis with purity of 99.9%. Required contents having oxides of Bismuth, oxides of lithium & boric acid well mixed and melted followed by annealing within temperature range 100 to 150^{o} C which were further cooled to ambient temperature.

Benzene as immersion liquid was used for estimating density values of glasses at ambient temperature with the help of Archimedes principle. All the prepared glasses were weighed in Benzene and air at 20^{0} Celsius. Following equation was used for finding the density values

$$\rho = A/(A-B)\times 0.787 \qquad (1)$$

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Where density is denoted by ρ, A denotes weight when suspended in air, B is weight when immersed in liquid medium, benzene density was taken to be 0.787 gcm^{-3} at room temperature. Molar volume (V_g), mole fraction values & density of the synthesized glasses are given in table number 1.

Diffractions using X rays were done to confirm non-crystalline nature of the glass systems under investigation. Glass material for analysis was taken in powder form. Diffraction was done with the help of Philips (PW 1710) diffractrometer and CuKα rays were taken for scanning at a rate (2θ/s) of 0.030 with starting value of angle(2θ) at 5.01 degrees & ending angle value of (2θ) at 60 degrees.. Non presence of peaks of crystallization recorded patterndepicts the non-crystalline nature of glasses.

.The mass- attenuation (μ) coefficient of synthesized glasses was estimated by using NIST-XCOM software [4-5]. Half Value layers (HVL) were estimated by mass- attenuation coefficient with following formula:

$$HVL = (0.693) / (\mu) \quad (2)$$

Result and Discussion

Molar volume & Densities value:

Molar volume & values for the Density for the synthesized glass materials presented in table number 1 shows that Density (ρ) increases from 2.12 gcm^{-3} to 6.21 gcm^{-3}in G8 showing the effect of increment in the mole percentage of Li_2O and for G8 replacement of Bi_2O_3at the cost of Li_2O .The values of molar volume shows a decrease from G1 to G7 confirming that the

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structure is becoming more and more compact as the mole fraction of Li_2O is increased at the expense of B_2O_3 . This is assigned due to the increases in more number of BOs (bridged oxygens) [6-7]. For 0.45 Bi_2O_3 0.55 B_2O_3value of density is maximum for the investigated glass and the V_g (molar volume) or the .50 Li_2O 0.50 B_2O_3 is minimum. The maximum molar volume corresponds to the G8 , which can be attributed to the increased mole fractions of Bi_2O_3 results the change in role of Bi_2O_3 from glass modifier role to glass former role corresponding to more mole percentage causing for the more openness.

Table Number 1.- Mole fraction, density in units gcm^{-3} (ρ), molar volume (V_m)

Glass Sample Name	Li2O	Bi2O3	B2O3	ρ(gcm^{-3})	V_m (cm^3 mol^{-1})
G1	0.2	0	0.8	2.12	29.091
G2	0.24	0	0.76	2.17	27.688
G3	0.3	0	0.7	2.24	25.758
G4	0.35	0	0.65	2.27	24.542
G5	0.4	0	0.6	2.29	23.460
G6	0.45	0	0.55	2.29	22.593
G7	0.5	0	0.5	2.29	21.725
G8	0	0.45	0.55	6.21	39.934

Coefficient of Mass- attenuation (μ) & effective- atomic (Z_{eff}) number values

Coefficient of mass- attenuation (μ) of the investigated systems listed in table number 2 within energy limits 1KeV to 100 GeV values. As seen clearly the mass -attenuation coefficients are quiet largecorresponding to very less energy limits.Corresponding to this energy limit the dominating phenomenon is photoelectric-effect. Mass- attenuation (μ) coefficients values as

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seen clearly as in table number 2 highlights fast decrement achieving low value for intermediate energy limits. If we change the energy limit from intermediate energy limits which corresponds to Compton phenomenon of scattering to energy limits with high values which corresponds pair -production mechanism, mass- attenuation coefficient values first undergo through increment, at very high energy limits the value is steady[7-8].

Z_{eff} (Effective- atomic number) is calculated found by the formula:

$$Z_{eff} = \sigma_{avg} / \sigma_{electronic} \quad (3)$$

σ_{avg} (average atomic- cross section), is calculated by the relation:

$$\sigma_{avg} = \sigma_{molecular} / \sum_i n_i \quad (4)$$

Total molecular interaction- crosssection is $\sigma_{molecular}$

$\sigma_{molecular} = ((\mu/\rho)\, M'/(N_A))$,where $M' = \sum(n_i A_i)$ known as molar mass value , A_i weight of the atom, number of formula unit isn_i&N_A is Avogadro constant of elements forming the glass structure.

$\sigma_{electronic}$(Average electronic- cross-section) is calculated by the relation:

$$\sigma_{electronic} = (1/N_A \sum f_j A_k / Z_j(\mu/\rho)) \quad (5)$$

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Here $f_j = (n_i / (\sum n_k))$ is fraction of abundance for j^{th} element for the number of atoms & Z_i denotes atomic number for jth element.

Half layer value & the Effective-atomic numbers

Absorption &scattering of γ (gamma)- photons are function of Z_{eff} (effective atomic) number for various materials. Z_{eff} (effective- atomic number) is estimated with the help of equation number 3 and are plotted in the figure number 1.

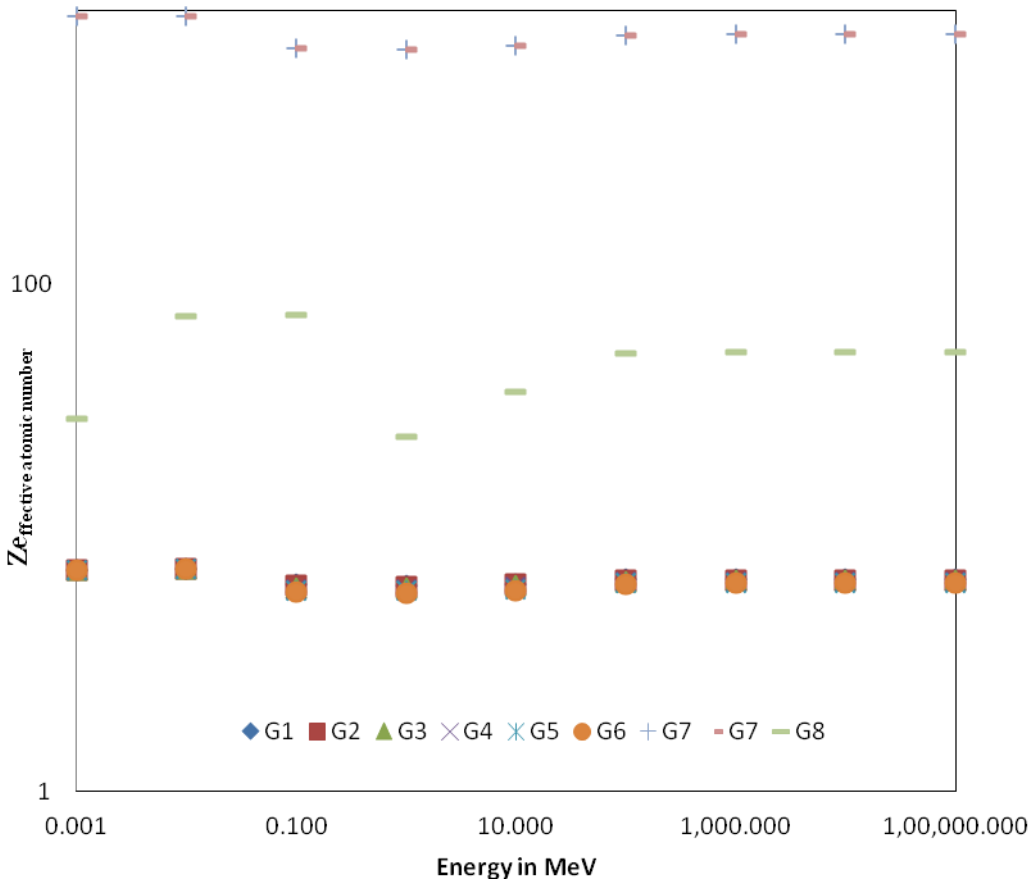

Figure 1 Plot of $Z_{Effective\ atomic\ number}$ of synthesized glass materials at various photon energies

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As clearly seen from the graph 1 for all the samples the Z_{eff} (effective atomic number) steadily enhances upto the energy limit 10^{-1} MeV, then it steadily shows decrement by the energy limit to 10^{0}MeV thereafter it shows increment up to 10^{2} MeVbeyond which Z_{eff} almost remains constant. The observed change for the effective number values (Z_{eff}), for the materials under investigation are because of domination of various mechanisms consistingof phenomenon of photoelectric effect, coherent& incoherent scattering. Photoelectric phenomenon is dominating factor at low energy responsible for more values of Z_{eff} (effective- atomic number), scattering phenomenon dominates at high energies resulting in less value of effective atomic number [9-10]. The above mentioned factors accounts Therefore, the Z_{eff} in total γ (gamma) photon interaction process changes for low energy to higher energy from high value to low value respectively. Further it is the dependence upon interaction phenomenon which dominates. The rate of increase for the values of Z_{eff} (effective- atomic number) depends on the change of low atomic number metal with the high atomic number metal. In the present case the linear rise is observed.

Table 2. Values of Mass attenuation coefficients (cm^2/g)at various energies in MeV.

Sample Name	μ/ρ(Mass Attenuation coefficient)								
	.003	**.01**	**0.1**	**1**	**10**	**100**	**1000**	**10000**	**100000**
G1	3.451E+03	4.38E+00	1.50E-01	6.201E-02	1.971E-02	1.581E-02	1.816E-02	1.951E-02	1.961E-02
G2	3.43E+03	4.36E+00	1.49E-01	6.191E-02	1.97E-02	1.58E-02	1.851E-02	1.941E-02	1.95E-02
G3	3.39E+03	4.32E+00	1.49E-01	6.18E-02	1.961E-02	1.571E-02	1.841E-02	1.931E-02	1.941E-02
G4	3.36E+03	4.28E+00	1.49E-01	6.172E-02	1.961E-02	1.561E-02	1.831E-02	1.911E-02	1.913E-02

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G5	3.331E+03	4.241E+00	1.49E-01	6.17E-02	1.95E-02	1.551E-02	1.821E-02	1.901E-02	1.92E-02
G6	3.29E+03	4.20E+00	1.48E-01	6.161E-02	1.9521E-02	1.541E-02	1.801E-02	1.891E-02	1.901E-02
G7	3.54E+03	4.49E+00	1.501E-01	6.22E-02	1.991E-02	1.611E-02	1.891E-02	1.981E-02	2.001E-02
G8	5.08E+03	1.04E+02	4.39E+00	6.99E-02	4.30E-02	7.55E-02	9.281E-02	9.641E-02	9.701E-02

HVL (Half layer value parameter) was calculated from mass attenuation with the help of relation given in equation number 2. Table 3 shows observed values of Values of HVL (Half layer value parameter). It can be seen that HVL for investigated glasses is minimum for the glass sample G8.

For the binary borate glass system having oxide of bismuth the value of HVL is minimum. From the table it can be concluded that out of the all the system the minimum value of HVL can be attributed to the substitution of low mass metal with the metal atom with more mass [8,10].

Table 3: HVL for synthesized glasses at various energies in MeV

Sample Name	**HVL (cm)**								
	0.001	0.01	0.1	1	10	100	1000	10000	100000
G1	9.475E-05	0.07462	2.18716	5.27559	16.598	20.6688	17.5796	16.80273	16.674204
G2	9.316E-05	0.07332	2.13963	5.15903	16.2403	20.2695	17.2488	16.483334	16.356733
G3	9.118E-05	0.07172	2.07694	5.00508	15.7809	19.7614	16.8187	16.076067	15.951767
G4	9.0831E-05	0.07138	2.05225	4.94614	15.6122	19.6004	16.6963	15.954778	15.838924
G5	9.0958E-05	0.07143	2.03706	4.9093	15.5235	19.5547	16.6597	15.923589	15.798926
G6	9.198E-05	0.07216	2.04118	4.91727	15.5634	19.6819	16.7798	16.033232	15.915217
G7	8.5414E-05	0.0674	2.01671	4.86511	15.2497	18.8368	15.9909	15.288254	15.173304
G8	2.1995E-05	0.00107	0.02543	1.59763	2.59596	1.4783	1.20339	1.1580704	1.1513812

ρ (density of the material) along with the mole percentage are the deciding factors for the half layer value parameter. In addition the rigidity of glass structure plays its role in deciding the

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above mentioned parameter. Weather a given material can be used in applications for shielding

Type	**Weight Fraction**														ρ
	H atom	B atom	C atom	O atom	Na atom	Mg atom	Al atom	Si atom	S atom	K atom	Ca atom	Cr atom	Fe atom	Ba atom	
Ordinary concrete	0.100		0.001	0.529	0.016	0.002	0.033	0.337		0.013	0.044		0.014		2.3 gm cm^{-3}
Barite concrete	0.008	0.011		0.347		0.002	0.004	0.014	0.099		0.083		0.004	0.423	3.5 gm cm^{-}

from harmful radiations the thickness at which intensity is reduced to 50% is important, which is measure of HVL. Table number 4 contains the values of constituents for the standard concretes. The system under investigation is compared with concretes for the thickness requirement in terms of HVL values.

Table 4. Weight fraction concretes

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Ferrite concrete	0.028			0.455		0.001	0.003	0.012	.0007		0.059		0.437		4.5 gm cm^{-}
Chromite concrete			.0006	0.367	0.008	0.059	0.053	0.044	0.006		0.036	0.342	.0804		3.27 gm cm^{-}
Serpentite concrete	0.012	0.0061		0.513		0.170	0.021	0.158	0.004		0.067		0.044		1.95 gm cm^{-}

Synthesized glass material having 45 mole percentage of bismuth oxide and 55 mole percentage of borate is chosen for comparing with concretes, due to fact that the half value layer for this glassy system is least in all the synthesized materials. Figure 2 depicts the graph of the Half Layer Values (HVL) for the concretes as given in table number 4 and G8 sample. From graph we can observe that out of all the synthesized glasses, the sample (G8), value of HVL corresponding to all the energies is less as in compared with concretes.

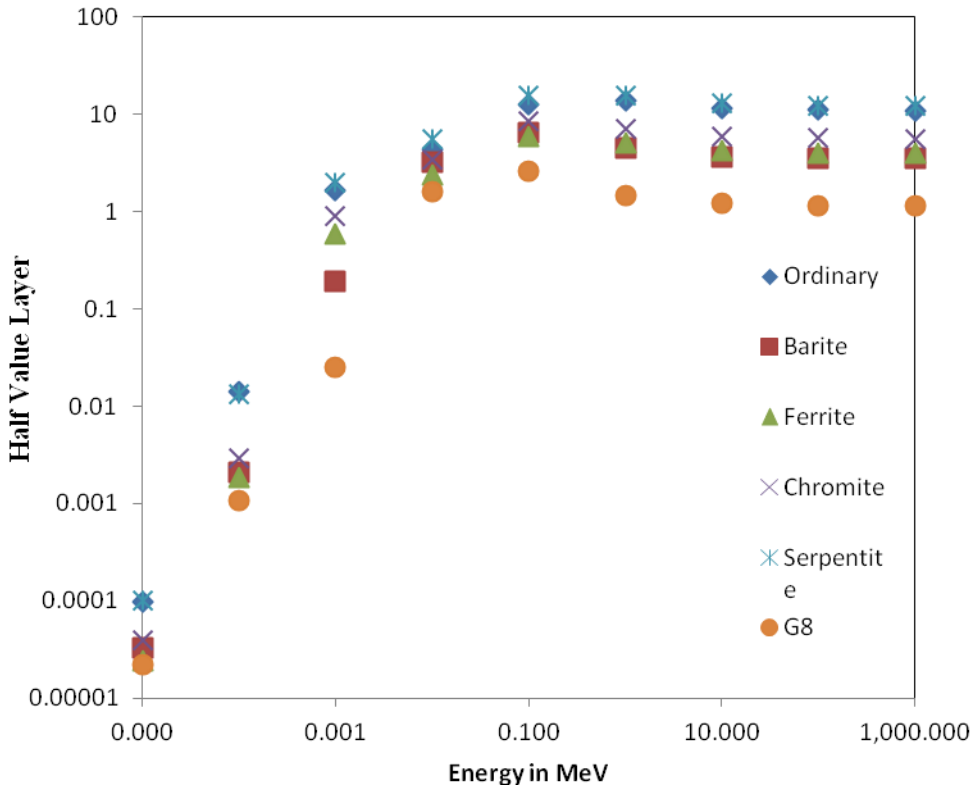

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Figure 2. Graphical presentation of HVL(cm) for G8 and concrete as energy of gamma ray

Conclusion:

Within this work , we analyzed the binary borate glasses containing lithium & bismuth for γ–photon shielding parameters with respect to values of mass -attenuation and thickness requirement in terms of half layer (HVL) value. It is concluded that the glassy material G8 corresponding has maximum mass attenuation (μ) coefficient and minimum half value (HVL) layer as compared with concretes. The minimum HVL value suggests that these can be used as alternate to concretes and bismuth based heavy metal oxide glasses are less toxic and can be candidates where lead is used as heavy metal which is toxic to environment.

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