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Effect of a Heavy Metal Oxide on the Radiation Shielding Parameters for Some Borate Glasses.

Rajinder Singh Kaundal*.

Department of Physics, School of Physical Sciences, Lovely Professional University, Phagwara, Punjab-144411, India.

ABSTRACT

Glasses of the system 0.45M-0.55B_2O_3 where M=Li_2O, Na_2O, K_2O, Bi_2O_3 were prepared using the melt quenching technique. In order to evaluate gamma-ray shielding properties for glass samples, mass attenuation coefficients have been calculated with the XCOM computer program. The values of effective atomic number at various photon energies is calculated. Values of half value layers have been compared with barite concrete. Density and molar volume studies have been undertaken to get the idea regarding rigidity of glass network

Keywords: Borate Glasses, Mass attenuation coefficient, Half value layer, Effective atomic number

Corresponding author

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INTRODUCTION

Developing materials which can be used in the environment of high radiation exposure has become the important research area. These materials can play vital role in medical, engineering and many other scientific applications. The data based on mass attenuation coefficient and half value layer can serve the purpose of identifying these materials. For reactors and other areas where radiation exposure is high concrete is widely used as the radiation shielding material because it is cheap and can be easily mold into the desired design. In spite of all these advantages some limitation are also associated with the concretes like it is not transparent to visible light thus restricting one to see through it. Secondly when it is exposed to the radiations for a longer period of time its mechanical strength is reduced. So it is desired to have materials which are transparent and have better shielding properties in terms of lesser volume requirement. Now a days heavy metal glasses are proving to be the promising candidates as an alternate to the conventional shielding material like concrete. These have considerable technological applications due to their density, high refractive index and low melting point [1-2].

MATERIALS AND METHODS

Glass samples of the chemical compositions given in table1 have been prepared by using the melt quenching technique All the chemicals used in the sample preparation were of analytical reagent (AR) grade having percentage purity of 99.9%. Appropriate amounts of $L_{i2}Co_3$, Na_2CO_3,K_2CO_3,Bi_2O_3, and H_3BO_3 were mixed thoroughly. Mixture was then taken in porcelain crucible and was melted and the melt was kept at the same temperature for 2 hours. Melt was quickly poured into preheated moulds in the temperature region of 200 to 250^0 C followed by cooling down to room temperature.

Densities of the samples at room temperature were measured by using Archmede's principle with Benzene as immersion liquid. Glass samples were weighed in air and when immersed in Benzene at 20^0 C. The density was calculated by using the formula

$$\rho = a/(a-b)\times 0.787 \qquad (1)$$

Where ρ is the density of glass sample, a is weight of sample in air, b is weight of glass sample in Benzene and 0.787 is the density of Benzene at 20^0 C. Chemical composition along with density and molar volume of the prepared glass samples is given in table 1.

Table 1: Chemical compositions, density and molar volume of prepared glass samples

Sample Name	Li_2O	Na_2O	K_2O	Bi_2O_3	B_2O_3	Density(gcm^{-3})	Molar Volume(cm^3 mol^{-1})
S1	0.45	.....	.....	.....	0.55	2.31	22.3969697
S2	.....	0.45	.....	.....	0.55	2.48	26.68629032
S3	.....	.....	0.45	.....	0.55	2.37	34.1185654
S4	.....	.....		0.45	0.55	6.19	40.0631664

To confirm the amorphous nature glass samples XRD measurements were carried out on the prepared samples. Samples were crushed to fine powder form for X-ray diffraction studies. A Philips PW 1710 diffractrometer was used during the investigations. Radiation used was CuKαThe pattern was recorded at a scanning rate (2θs of 0.030 with start angle(2θat 5.010^0 and end angle(2θ at 60.0^0. Absence of crystallization peak in XRD data shows that prepared samples are amorphous.

The mass attenuation coefficient of prepared samples is evaluated by using WIN XCOM [3-4] developed by NIST. HVL have been determined by mass attenuaton coefficient by using the relation

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

Effective atomic number can be calculated by using relation

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$$Z_{eff} = \sigma_{t,a} / \sigma_{t,el} \quad (3)$$

Where the average atomic cross-section, $\sigma_{t,a}$ is evaluated by using equation

$$\sigma_{t,a} = \sigma_{t,m} / \sum_i n_i \quad (4)$$

$\sigma_{t,m}$ is the total molecular interaction cross-section

$\sigma_{t,m} = (\mu/\rho)\, M/N_A$,where $M=\sum n_i A_i$,where $M=\sum n_i A_i$ is the molar mass, N_A is Avogadro's constant and n_i and A_i are the number of formula units and atomic weight, respectively of constituent elements.

Average electronic cross-section, $\sigma_{t,el}$ is given by

$$\sigma_{t,el} = 1/N_A \sum f_i A_i / Z_i \, (\mu/\rho) \quad (5)$$

where $f_i = n_i / \sum n_j$ is fractional abundance of element i with respect to number of atoms and Z_i is atomic number of i element.

RESULTS AND DISCUSSIONS

Density and molar volume values of the prepared samples are shown in table1. The values of density increase from S1 to S4 showing the effect of changing a light metal atom with the heavier metal atom. The values of molar volume also show linear increase depicting that structure becomes more and more open as light metal atom is changed with heavier one.[5] The value of molar volume is maximum for the composition corresponding to Bi. Ti can be due to the fact that Bi ions play dual role in the glass structure. At higher mole fraction the role of Bi ions in the glass structure is of glass former. The values of mass attenuation coefficients for the various samples are shown in table 2 from energy range 1KeV to 100 GeV. It can be observed that the mass attenuation coefficient values are very high in low energy range for which photoelectric effect is dominant. The values of mass attenuation coefficients as evident from table 2 shows rapid decrease attaining minimum value in the intermediate energy range. As one moves from intermediate energy range corresponding to Compton scattering region to high energy range corresponding to pair production the values of mass attenuation coefficient first show increase and at very high values of the energy the values become almost constant.[6-7]

Table2: Mass attenuation coefficients for prepared glass samples at different energies

Sample	Mass Attenuation coefficient μ/ρ (cm^2/g)								
	0.001 MeV	0.01 MeV	0.1 MeV	1 MeV	10 MeV	100 MeV	1000 MeV	10000 MeV	100000 MeV
S1	3291	4.195	0.1483	0.06156	0.01945	0.01538	0.01804	0.01888	0.01902
S2	2755	8.117	0.1533	0.062	0.02058	0.0181	0.02145	0.0224	0.02257
S3	3863	37.22	0.1875	0.06233	0.02309	0.02435	0.02941	0.03074	0.03095
S4	5075	104.4	4.389	0.06987	0.043	0.07551	0.09276	0.09639	0.09695

The scattering and absorption of gamma radiations are related to the effective atomic number of the materials. These values are calculated using equation 3 and variation for the prepared samples is shown in figure 1. It can be seen from the figure that for all the samples the Z_{eff} steadily increases up to 10^{-2}MeV, then it steadily decreases up to 10^{0}MeV after which it increases up to 10^{2} MeV after this energy the values of Z_{eff} almost remains constant. The variation of Z_{eff}, value with energy for the samples materials may can be assigned due to the relative domination of different mechanisms mainly photoelectric effect, coherent scattering and incoherent scattering. At low energies, where photoelectric effect dominates, Z_{eff} is more and at higher energies, where scattering dominates, Z_{eff} is less.[8] Therefore, the Z_{eff} for total gamma ray interaction varies from a higher value at lower energies to a lower value at higher energies depending on the relative domination of the partial gamma ray interaction processes. Effective atomic numbers increases

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linearly as we change the light metal atom with heavier metal atom. Value of effective number is maximum for the sample ontaining Bi atom. i.e. sample S5

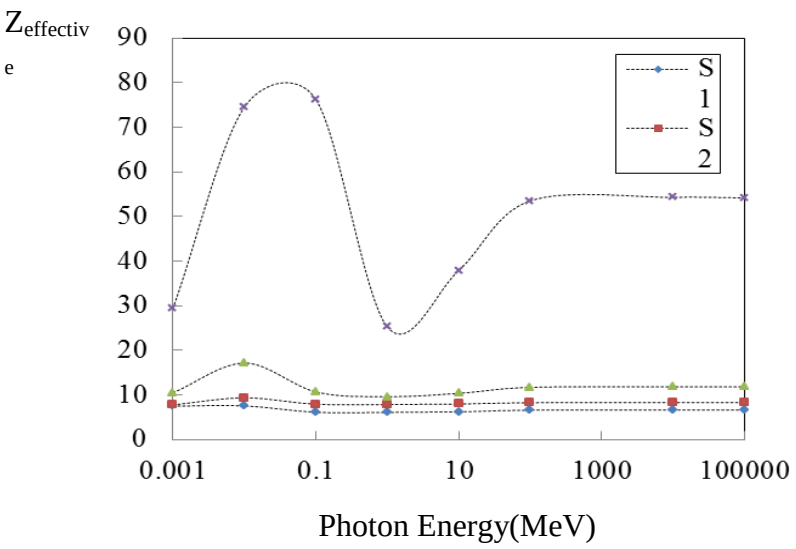

Figure1: Plot of effective atomic number verses photon energy for the glass samples

Sample	HVL(cm)								
	0.001 MeV	0.01 MeV	0.1 MeV	1 MeV	10 MeV	100 MeV	1000 MeV	10000 MeV	100000 MeV
S1	9.12E-05	0.071534	2.02351	4.874701	15.42862	19.51148	16.63451	15.89441632	15.77742272
S2	0.000101	0.034436	1.823328	4.508325	13.58193	15.44288	13.03105	12.47839862	12.38440979
S3	7.57E-05	0.007858	1.559944	4.692595	12.66736	12.01189	9.945238	9.514946372	9.450386154
S4	2.21E-05	0.001073	0.025515	1.602792	2.604351	1.483076	1.207278	1.161812179	1.15510135

Half value layer parameter is calculated from the linear attenuation coefficient using equation 2. Values of HVL are given in table 3. It can be seen that HVL decreases with replacement of light metal with the heavy metal.[9-11]

Table 3: HVL values for prepared glass samples at different energies.

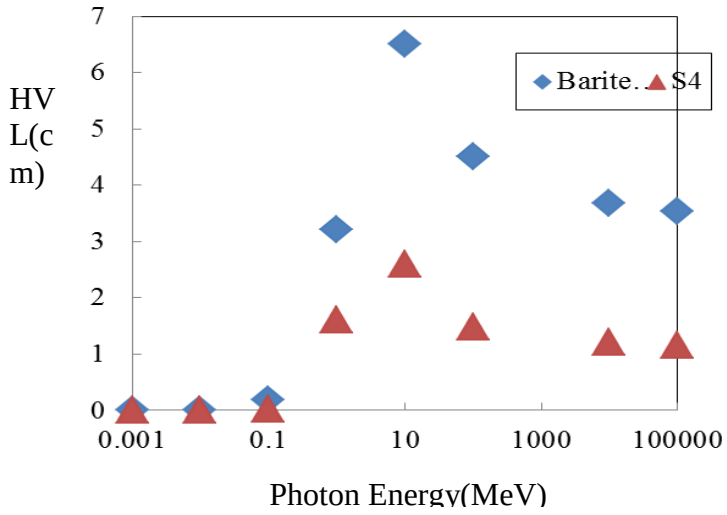

Figure 2: Plot of HVL(cm) verses photon energy for barite concrete and S4 as a function of photon energy

HVL is not only composition dependent but it also dependent upon the density of material which is further related to the structural arrangements of constituents of composite material. This parameter is very important for the materials to be used as the radiation shield. For this purpose, HVL values of the prepared glasses have been compared with some standard radiation shielding concretes. For this barite concrete is taken for the comparison purpose since its HVL value is minimum among all the concretes. Figure 2 shows comparative plot of the HVL value for barite concrete and S4 sample. It can be clearly seen that for the prepared sample (S4), value of HVL at all the energies is lesser than the barite concrete .

CONCLUSION

Bi containing grasses are found to have lowest HVL values in all the prepared samples .It is concluded that the Bi containing glasses can be used as an alternate to the radiation shielding materials. Further these are transparent to visible light and require lesser volume as compared to concretes which are opaque and require much larger volume.

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