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Comparative Study of Radiation Shielding Parameters for Binary Oxide Glasses

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ABSTRACT

Melt and quench technique was used for the preparation of glassy samples of the composition 0.40 MO-0.60 B_2O_3 where MO contains oxides of lithium, sodium, potassium and bismuth. XCOM computer program is used for the evaluation of gamma-ray shielding parameters of the prepared glass samples. Further the values of mass attenuation coefficients and effective atomic number at various photon energies is calculated. Values of half value layers have been compared with concretes. Density and molar volume studies have been carried out to get the idea regarding rigidity of glass network.

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

INTRODUCTION

The study of interaction of nuclear radiations with matter is the important research area for the development of materials which can be used in high radiation environment.These radiation shielding materials have great importance for many scientific, engineering and medical applications. The data based on mass attenuation coefficient and half value layer is very useful for the purpose to identify the various radiation shielding materials. In the environment of high radiation exposure concrete is used as radiation shielding material because it is cheap and it can be molded easily into any 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 to visible light 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[1-5]. These have considerable technological applications due to their density, high refractive index and low melting point[6-7].

MATERIALS AND COMPUTATIONAL METHOD

Sample preparation, X-ray and density measurements

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 Li_2CO_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°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°C. The density was calculated by using the formula.

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°C. Chemical composition along with density and molar volume of the prepared glass samples is given in table 1.

$$p = a/(a-b) \times 0.787 \quad (1)$$

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 CuKa. The pattern was recorded at a scanning rate (2θ/s) of 0.030 with start angle (2θ) at 5.010° and end angle (2θ) at 60.0°. Absence of crystallization peak in XRD data shows that prepared samples are amorphous.

Linear attenuation coefficients and effective atomic number

The mass attenuation coefficient of prepared samples is evaluated by using WIN XCOM[3-4] developed by NIST. Several authors and researchers have experimentally measured mass attenuation coefficients of different materials including silicate and borate glasses. Excellent agreement has been observed between the experimental and theoretical data obtained by XCOM software. In light of this it is possible to estimate mass attenuation coefficient for our glass system with reasonable accuracy by XCOM software[8-10].

HVL have been determined by mass attenuation coefficient by using the relation.

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

Effective atomic number can be calculated by using relation.

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

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

$$\sigma_{t,a} = \sigma_{t,m}/\Sigma_j n_j \quad (4)$$

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

$\sigma_{t,m} = (\mu/p)M/N_A$, Where $M = n_j A_j$ is the mole mass, N_A is Avogadro's constant and n_j and A_j are the number of formula units and atomic weight, respectively of constituent elements.

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

$$\sigma_{t,el} = 1/N_A \Sigma f_j A_j / Z(\mu/p) \quad (5)$$

where $f_i = n_i/\Sigma n_j$ 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

Density and molar volume values of the prepared samples are shown in table1. The values of density increase from GS1 to GS4 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.[11] The value of molar volume is maximum for the composition corresponding to Bi. It 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.

Linear attenuation coefficients

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.[12-13]

Effective atomic numbers and half value layer

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

Table. 1: Chemical compositions, density (r), molar volume (V_m).

Sample Name	Li_2O	Na_2O	K_2O	Bi_2O_3	B_2O_3	r(gcm^{-3})	V_m (cm^3 mol^{-1})
GS1	0.40	.....	.....	.....	0.60	2.29	23.46026
GS2	.....	0.40	.....	.....	0.60	2.44	27.28033
GS3	.....	.....	0.40	.....	0.60	2.32	34.31552
GS4	.....	.....		0.40	0.60	5.79	39.40794

Table. 2 : Mass attenuation coefficients for prepared glass samples at different energies.

Sample	Mass Attenuation coefficient μ/p (cm^2/g)								
	0.001 MeV	0.01 MeV	0.1 MeV	1 MeV	10 MeV	100 MeV	1000 MeV	10000 MeV	100000 MeV
GS1	3328	4.238	0.1486	0.06166	0.0195	0.01548	0.01817	0.01901	0.01916
GS2	2847	7.696	0.1529	0.06203	0.02049	0.01786	0.02116	0.0221	0.02227
GS3	3832	34.04	0.1838	0.06232	0.02277	0.02355	0.02839	0.02968	0.02989
GS4	5023	101	4.245	0.06962	0.04222	0.07349	0.09025	0.0938	0.09434

is shown in Fig. 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[14]. 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 linearly as we change the light metal atom with heavier metal atom. Value of effective number is maximum for the sample containing Bi atom. i.e. sample GS4 .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[14-16].

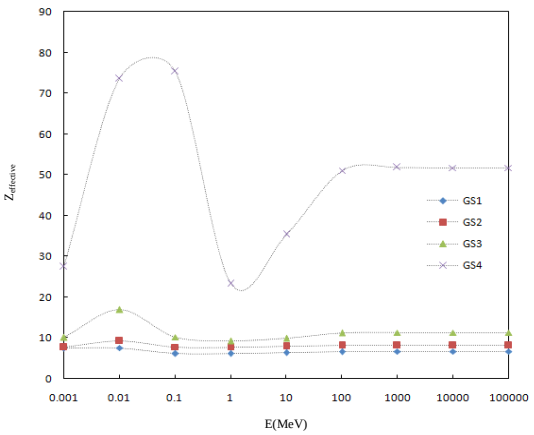

Fig. 1. Plot of Effective atomic number for the prepared glass samples as a function of photon energy.

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

Sample	HVL(cm)								
	0.001 MeV	0.01 MeV	0.1 MeV	1 MeV	10 MeV	100 MeV	1000 MeV	10000 MeV	100000 MeV
GS1	9.1E-05	0.071427	2.037062	4.9093	15.52346	19.55474	16.65974	15.92359	15.79893
GS2	9.98E-05	0.036915	1.858066	4.580015	13.86522	15.90696	13.4262	12.85513	12.757
GS3	7.8 E-05	0.008778	1.625643	4.794498	13.12223	12.68761	10.52459	10.06715	9.96424
GS4	2.38E-05	0.001185	0.028203	1.719673	2.83571	1.629115	1.326578	1.276372	1.269066

Table. 4: Chemical composition of concretes

Concretes	Wt. Fraction														Density
	H	B	C	O	Na	Mg	Al	Si	S	K	Ca	Cr	Fe	Ba	
Ordinary	0.1000	..	0.0010	0.5291	0.0160	0.0020	0.0338	0.3370	..	0.0130	0.0440	..	0.0140	…	2.3
Barite	0.0083	0.0115	..	0.3475	..	0.0022	0.0044	0.0148	0.0997	..	0.0834	…	0.0047	0.4237	3.5
Ferrite	0.0280	..	…	0.4554	..	0.0019	0.0038	0.0128	0.0007	..	0.0595	…	0.4378	..	4.5
Chromite	…	..	0.0006	0.3670	0.0088	0.0593	0.0535	0.0443	0.0061	..	0.0364	0.3423	0.0804	..	3.27
Serpentite	0.0128	0.0061	..	0.5136	…	0.1705	0.0215	0.1587	0.0046	..	0.0677	…	0.0441	..	1.95

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,

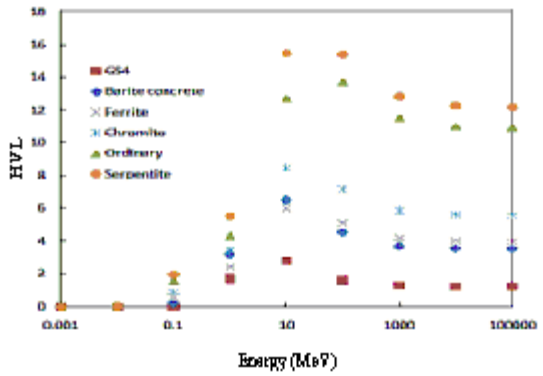

Fig. 2. Plot of HVL(cm) for various concretes and GS4 as a function of photon energy.

HVL values of the prepared glasses have been compared with some standard radiation shielding concretes (Table 4). For this glass sample GS4 is taken for the comparison purpose since its HVL value is minimum among all the prepared glass samples. Fig. 2 shows comparative plot of the HVL value for various concretes and GS4 sample. It can be clearly seen that for the prepared sample (GS4), value of HVL at all the energies is lesser than the concretes.

CONCLUSIONS

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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