Determination of Radiation Attenuation Coefficient on Lithium Barium Bismuth Phosphate Glasses at 662 keV

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Abstract

The aim of this research to study of the mass attenuation coefficients of lithium barium bismuth phosphate (LBBP) glasses which were prepared by the melt quenching technique. Cs-137 source was used for this experiment and measured at 662 keV gamma ray energy. The theoretical values were calculated by using WinXCom program and compared with the experimental ones. The results showed that the mass attenuation coefficients of LBBP were decrease with the increasing of BaO concentration and those had higher values of mass attenuation coefficients than standard shielding concretes.

Keywords: mass attenuation coefficient, radiation shielding, phosphate glass

1. Introduction

Nowadays, the scientific and technological advancement play a more important role in human life. Radiation utilization is one of the most important technologies both in human health, industries, medical and agriculture because the radiation is a particle that cannot be touched when entering the body. Therefore, in radiation practice, the radiation protective equipment is required for the safety of workers and those who involved. The most radiation shielding materials commonly used are concrete because it is inexpensive and adaptable for any construction design. There are however many drawbacks associated with using of concrete, such as considerable variability in its composition and water content. This variation results in uncertainty in calculations for shield design predictions of the radiation distribution and attenuation in the shield. Water contents have the disadvantages of decreasing both density and structural strength of concrete. However, its drawback is the loss of water when concrete becomes hot by absorption of energy from radiation. In addition, concrete is opaque to visible light and thus it is difficult to see through the concrete-based shield and the other type of radiation shielding materials is lead oxide glasses (Bashter et al ., 1997: 1389-1401) but nowadays it has been restricted in various radiation shielding applications due to the expression of the toxicity of lead to children and adults as well as the environmental hazard of it and protectionism in the world economy.

In the recent years, glasses are an option that used as a radiation shielding material because there is a transparent property and can be contained by heavy metal oxide for absorbing x-rays or gamma rays and are much lower cost than those made from lead.

Among different glass hosts, oxide based phosphate glasses have unique physical and chemical properties due to their good structural properties such as relatively low phonon energy when compared to other glasses, low refractive index, high thermal expansion coefficient, low melting temperature, low glass transition temperature, low viscosity and high ultraviolet transmission (Doweidar et al., 2005: 91-96). These properties have made them ideal materials for fundamental studies of the glass transition and devitrification effects. However, their relative poor chemical durability precludes their practical utilization. Therefore, it has been noticed that the addition of metal oxides (MO) like BaO or Bi_2O_3 resulting in the formation of M-O(P) bonds, leads to improve the chemical durability and thermal stability of the phosphate glasses (Keawkhao et al., 2012: 976-981). These favorable features make phosphate glasses useful in radiation-intensive applications.

In this work, the lithium barium bismuth phosphate glasses have been investigated as replacement of lead-based glasses with suitable shielding properties. The mass attenuation coefficient of phosphate glasses based Bismuth and barium have been investigated experimentally at the photon energy of 662 keV and theoretically by using WinXcom program.

2. Experimental work

2.1 Sample preparation

Phosphate glasses with composition $5Li_2O$: $xBaO$: $(35-x)Bi_2O_3$: $60P_2O_5$ where x = 5, 10, 15, 20, 25 and 30 mol% have been prepared by conventional melt quenching technique using lab grad $(NH_4)_2HPO_4$, Li_2CO_3, Ba_2CO_3, and Bi_2O_3 as starting materials. The glass compositions are shown in Table 1. About 20 g of the batch composition was thoroughly ground in an agate mortar and this homogeneous mixture was taken into a porcelain crucible and heated in an electric furnace at 1000 °C for 2 h. The melt was air quenched by pouring it onto a preheated stainless steel mold and annealed at 500 °C for 3 h to remove thermal strains and then slowly allowed to cool to room temperature (RT). After that, the glass samples were cut and polished into 1.0×1.5×0.3 cm^3 shape to get good transparency and flat surfaces for optical measurements.

Table 2 Glass compositions and corresponding labels of glass system.

Labels	Glass composition (in mol%)	Thickness (cm)	Density (g/cm^3)
LBBP05	$5Li_2O$: $5BaO$: $30Bi_2O_3$: $60P_2O_5$	0.40	4.5557
LBBP10	$5Li_2O$: $10BaO$: $25Bi_2O_3$: $60P_2O_5$	0.30	4.4359
LBBP15	$5Li_2O$: $15BaO$: $20Bi_2O_3$: $60P_2O_5$	0.30	4.1653
LBBP20	$5Li_2O$: $20BaO$: $15Bi_2O_3$: $60P_2O_5$	0.35	3.8913
LBBP25	$5Li_2O$: $25BaO$: $10Bi_2O_3$: $60P_2O_5$	0.35	3.6654
LBBP30	$5Li_2O$: $30BaO$: $5Bi_2O_3$: $60P_2O_5$	0.40	3.4309

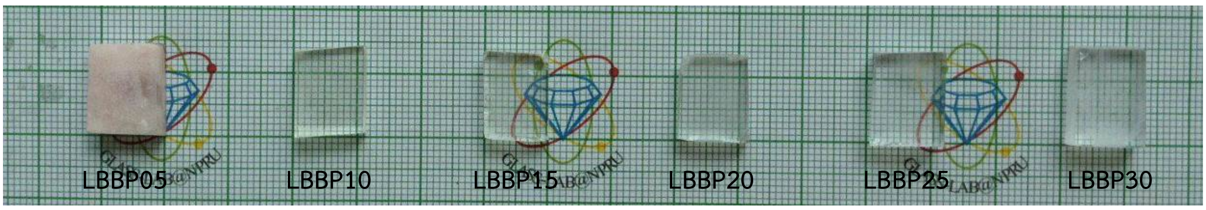

Fig. 1. Glass samples.

2.2 Mass attenuation coefficient

The experimental and theoretical values of mass attenuation coefficient were compared. In which, the experimental value obtained using a transmission method and then calculated using equation (1). For the theoretical value can be determined by using WinxCom program.

$$I_{(x)}=I_0.e^{-\mu\rho.\rho} \quad (1)$$

μ is the attenuation coefficient

ρ is the mass density.

I_0 is incident intensity, $I_{(x)}$ is emerge intensity

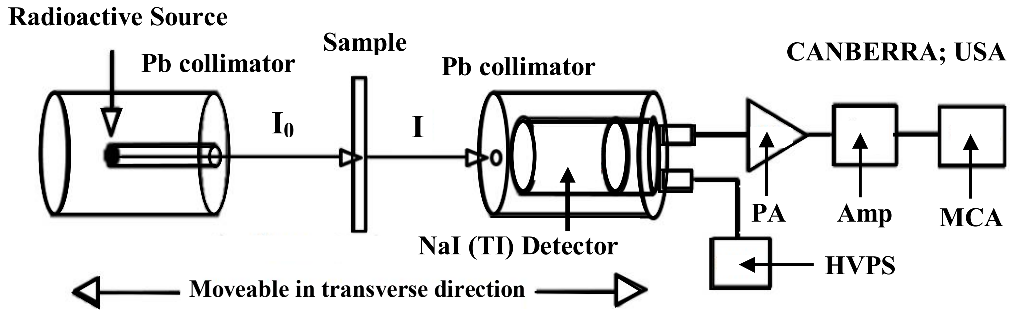

Fig. 2. Experimental setup of transmission method.

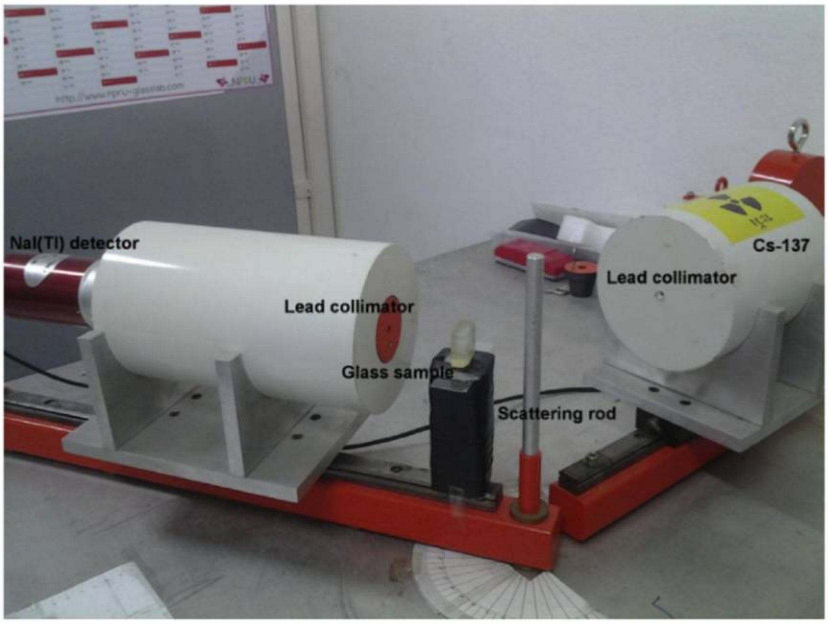

Fig. 3. Schematic of the mass attenuation coefficient measurement.

3. Result and discussion

Table 1 shows the measured thickness and density of glass sample with different concentration of BaO. In order to derive precise mass attenuation coefficients from the measured incident and transmitted gamma-ray intensities, it is necessary to have accurate data for thickness and density of the samples.

The mass attenuation coefficients of glass samples as shown in Table 2 were evaluated from gamma rays incidence (I_0) and transmitted (I) intensities and where its theoretical values were calculated by WinXCom program. In theoretical approach, it has been found that the mass attenuation coefficients were decreased with increasing of BaO content in glass matrix indicates the lower shielding properties. The decreased total photon interaction probability at this energy leads to the increase of the gamma-ray transmission with increasing amount of BaO. The experimental values of mass attenuation coefficient are in good agreement with the theoretical values with RD less than 0.28%.

The values of partial interactions with BaO concentration are shown in Table 2, which indicate that the Compton scattering gives a dominant contribution to the total mass attenuation coefficients for all studied glass samples and show the decrease with increasing of BaO concentration. In case of photoelectric and coherent scattering interaction are increased with decreasing of BaO concentration, however, both photoelectric and coherent scattering interactions are rather small for these glass samples at this energy (662 keV) comparing with Compton scattering. The pair production interaction does not occur because the energy is lower than 1.02 MeV.

Table 2 The mass attenation coefficients (μ_m) for total interaction and partial interaction of LBBP glasses system at 662 keV.

Samples	μ_m (cm^2/g) x 10^{-2}					
	Total interaction			Partial interaction (from Win X com)		
	Theory	Experiment	%RD	Compton scattering	Photoelectric effect	Coherent
LBBP05	8.606	8.597	0.01	6.932	1.427	0.248
LBBP10	8.431	8.438	0.02	6.941	1.260	0.230
LBBP15	8.257	8.260	0.28	6.951	1.093	0.212
LBBP20	8.082	8.110	0.20	6.961	0.926	0.195
LBBP25	7.908	7.992	0.28	6.971	0.759	0.177
LBBP30	7.733	7.798	0.20	6.981	0.592	0.160

Fig. 4., It is clearly seen that the total mass attenuation coefficient of glass system decreased with the decrease of Bi_2O_3 concentration at this energy, indicates the dependence of total mass attenuation coefficient values on the metal oxide content. This result shows the higher probability of photon interaction even more in the higher Bi_2O_3 content while the interaction is reduced with the decrease of Bi_2O_3 content. The experimental values of mass attenuation coefficient are in good agreement with the theoretical values. As can be seen in Fig. 4, the uncertainty for each experiment data is small, reflecting the good precision of the measurement. The partial interactions (photoelectric absorption, coherent and incoherent scatterings) of glass system were calculated and also shown in Fig. 4. The coherent scattering interactions were found to have a small effect on glass system in this energy. All partial interactions were higher with more Bi_2O_3 content. It can be noticed that the incoherent scattering is the main interaction that have a stronger effect on the total mass attenuation coefficient values in this glass system.

The mass attenuation coefficient of the prepared glass samples were acquired and presented in comparison with some standard radiation shielding material, taken from literature (I.I. Bashter, “Calculation of radiation attenuation coefficient for shielding concretes”. Vol.24, No 17, pp. 1387-1401, 1997). From Fig. 5., it can be seen that all the glasses in this work exhibited with higher values of mass attenuation coefficient against a basal-magnetite, hematite-serpentine, ilmenite-limonite, ilmenite, ordinary, steel-scrap, and steel-magnetite. The photon interaction probability is the total mass attenuation coefficient. The higher mass attenuation coefficient means more interaction of photon with material and hence giving an higher mass attenuation coefficient in the prepared glass samples compared with common radiation protective materials.

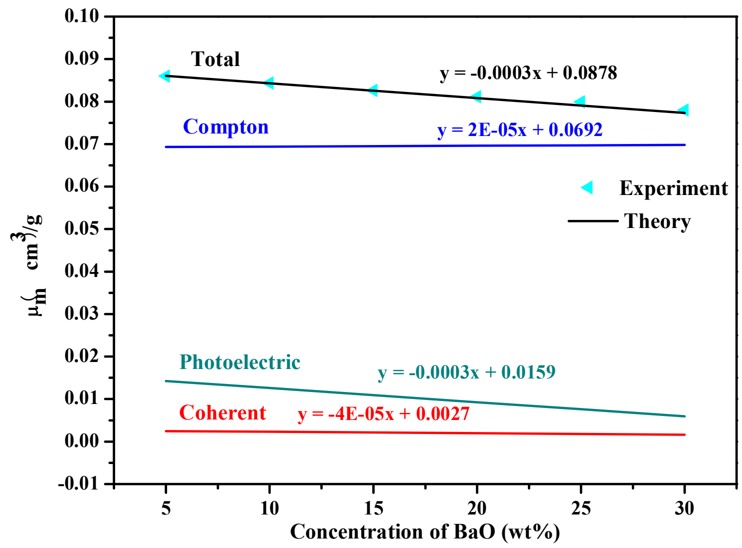

Fig. 4. The total mass attenuation coefficient of phosphate glasses system.

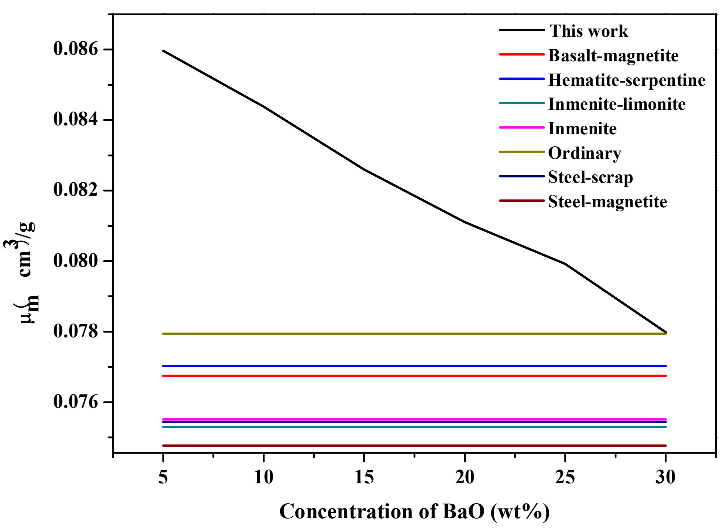

Fig. 5. Variation of mass attenuation coefficient at 662 keV as a function of BaO concentration compared with some standard radiation shielding materials.

4. Conclusions

In this work, the glass system with a chemical composition of $5Li_2O$: xBaO : (35-x)Bi_2O_3 : $60P_2O_5$ where x = 5, 10, 15, 20, 25, and 30 mol% have been prepared by conventional melt quenching technique. The mass attenuation coefficient values were measured at photon energy for 662 keV. The experimental values agree with the theoretical values, which are calculated from WinXCom program. The total mass attenuation coefficients decrease with increasing of BaO concentration, indicating that the photon interaction probability decreases with increasing of BaO concentration. From WinXCom calculation, the total mass attenuation coefficient is decreased due to the decrease of photoelectric absorption in glass system. However, Compton scattering gives dominant contribution of the total mass attenuation coefficient for the studied glass samples. All of the glass samples have been shown with higher mass attenuation coefficient than some standard radiation shielding materials at this energy, indicating the potential of the prepared glasses as a radiation shielding material with Pb-free advantage. In addition, these results are very useful in designing radiation shielding glass and reflecting influence of metal oxide content, BaO and Bi_2O_3, in radiation shielding glass.

5. Acknowledgement

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6. References

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