

# Lead Phosphate Glass Containing Boron and Lithium Oxides as a Shielding Material for Neutron- and Gamma-Radiation

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**Abstract** A glass system with chemical formula:  $x\text{Li}_2\text{O}-(50-x)\text{B}_2\text{O}_3-40\text{PbO}-10\text{P}_2\text{O}_5$  mole % is prepared to be used as radiation shield. The mass attenuation coefficient and half value layer of the glass system to gamma rays have been measured experimentally and compared with those determined from theoretical calculations using the mixture rule of WinXCom program. A database of effective mass removal cross-sections for fast neutrons is also introduced in this work.

**Keywords:** lead phosphate glasses, radiation shielding

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## 1. Introduction

Recently glass materials are one of the possible alternatives to concrete because they can be transparent to visible light and their properties can be modified by composition and preparation techniques. Several glasses have been developed for nuclear engineering application because they accomplish the double task of allowing visibility while absorbing radiation like gamma-rays and neutron, thus protection observer [1]. Phosphate glasses have unique properties which make them useful for a wide range of technical applications. However, these glasses have a relatively poor chemical durability [2] that often limits their usefulness. Several studies have shown that the chemical durability of phosphate glasses can be improved by the addition of various oxides such as PbO [3]. As a result, lead phosphate glass is now of interest for several technological and biocompatible applications [4]. It has been suggested that the addition of PbO results in the formation of P–O–Pb bond which improve the chemical durability [5]. PbO is known to play a dual role in many oxide glasses, as both a network modifier and a network former [7,8]. In PbO–P<sub>2</sub>O<sub>5</sub> glasses it was found that [6] Pb<sup>2+</sup> ions occupy a position between P–O–P layers. Recent analyses of the IR spectra of PbO–P<sub>2</sub>O<sub>5</sub> glasses [9] revealed that the addition of PbO to P<sub>2</sub>O<sub>5</sub> glasses causes a change in the short-range order structure of the phosphate matrix. For PbO < 50 mol%, PbO was found to enter the structure as a network modifier forming non-bridging oxygen ions (P=O–Pb<sup>2+</sup>–) [8].

The main objective of this work is to study shielding properties of this glass system. The Li<sub>2</sub>O contained in

glass are candidate materials for the development of radiation shielding glass.

## 2. Experimental Work

Analytically, pure grade chemicals were used to prepare the following glass samples according to the formula:  $x\text{Li}_2\text{O}-(50-x)\text{B}_2\text{O}_3-40\text{PbO}-10\text{P}_2\text{O}_5$  mole % where  $x=0, 5, 10, 15,$  and  $20$ . The batch mixtures were melted in porcelain crucibles at 1100 °C for two hours until homogeneous glasses were obtained and then annealed in a separate annealing furnace at 250 °C and then slowly cooled to the room temperature to remove any internal stresses. Samples have been obtained in circular shape of 2cm. Glass density measurements were measured at room temperature using the standard Archimedes method, with toluene as the immersion fluid of stable density (0.866g/cm<sup>3</sup>). Attenuation coefficients of the proposed glass system were measured in narrow beam transmission geometry by using a 200 × 200 NaI (TI) crystal detector with energy resolution of 12.5 % at 662 keV in conjunction with multi-channel analyzer (MCA). Samples were placed on specimen holder at distance of 10 cm from source. The distance between source and detector were 20cm. radioactive sources <sup>60</sup>Co and <sup>137</sup>Cs having activities (10 mCi) each was used for different photon energies. Incident and transmitted intensities of photons were measured on MCA for fixed preset time for each sample by selecting a narrow region symmetrical with respect to the centroid of the photo peak.

## 3. Results and Discussion

### 3.1. Density ( $\rho$ ) and Molar Volume

The density is a powerful tool capable of exploring the changes in the structure of glasses. The density is affected by the structural softening/ compactness [9], change in geometrical configuration, coordination number, cross-link density and dimension of interstitial spaces of the glass. In the studied glasses, it is noted that [Figure 1](#), the density decreases with increasing  $\text{Li}_2\text{O}$  content in the glass due to the replacement of the oxide ( $\text{B}_2\text{O}_3$ ) by lighter oxide ( $\text{Li}_2\text{O}$ ). So addition of  $\text{Li}_2\text{O}$  to network causes some type of structural rearrangement of the atoms. There is a possibility for the alteration of the geometrical configuration upon substitution of  $\text{Li}_2\text{O}$  into the glass

network. Molar volume is also an important physical property, it is noted that, the density decreases, congruent with an increase in the molar volume as the  $\text{LiO}_2$  content as shown in [Figure 1](#). Accordingly, the structure of the studied glasses will be expanded, but with compactness and high number of covalent bonds with an increase in the number of bridging oxygens. The compactness is evident from the increasing of the packing density and the increase in covalent bonds and bridging oxygens as the  $\text{B}_2\text{O}_3$  content decreases. This mechanism is in the contrary to the explanation of the expansion of the molar volume of glass systems increases on the expense of  $\text{B}_2\text{O}_3$  content.

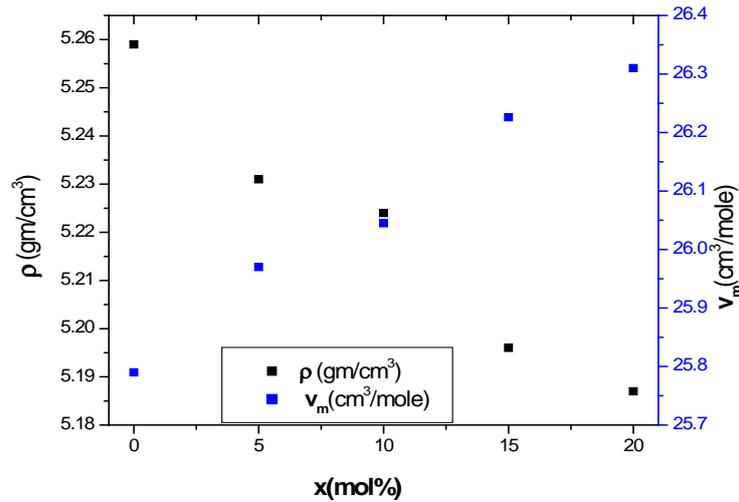


Figure 1. Dependence of the density and the molar volume of on the percentage of  $\text{LiO}_2$  content

### 3.2. Mass Attenuation Coefficients

The mass attenuation coefficients were estimated from the measured incident and transmitted gamma-ray intensities, as well as the thickness and density of each sample of the system, using Lambert–Beer law [10]. Theoretical curves are calculated by the WinXCom program [11]. [Figure 2](#) shows the experimental and theoretical results of the mass attenuation coefficients of

glass samples for different energies as a function of  $\text{LiO}_2$  concentration. A good agreement has been observed between experimental and theoretical values and the discrepancies are within the experimental errors. The results of mass attenuation coefficients almost constant or that the change is very simple with the mol% of  $\text{LiO}_2$  which may be due to the stability of lead in the glass system and the convergence of mass number for each of the  $\text{B}_2\text{O}_3$  and  $\text{Li}_2\text{O}$ .

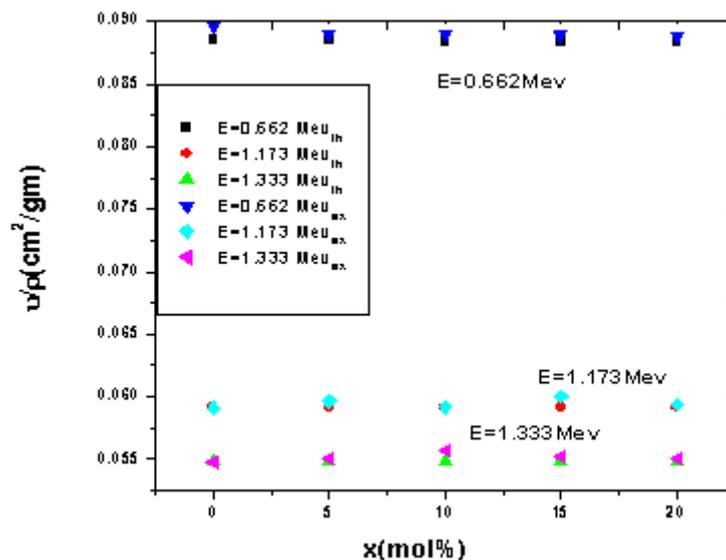


Figure 2. Experimental and theoretical values of mass attenuation coefficients ( $\mu_m$ ) as function of mol% of  $\text{LiO}$  in the glass system at 662, 1173 and 1332 keV

### 3.3. The Half Value Layer (HVL)

HVL is the thickness of a material required to reduce the intensity of the emergent radiation to half. It is used to describe the effectiveness of  $\gamma$ -ray shielding [10]. Figure 3 shows the behavior of the HVL for glasses with different

amounts of  $\text{LiO}_2$  and different  $\gamma$ -energies. This figure indicates that the half value layer (HVL) increases with increasing mole fractions of  $\text{LiO}_2$  in this glass system. This is due to the lower values of mass attenuation coefficients and densities for glass samples.

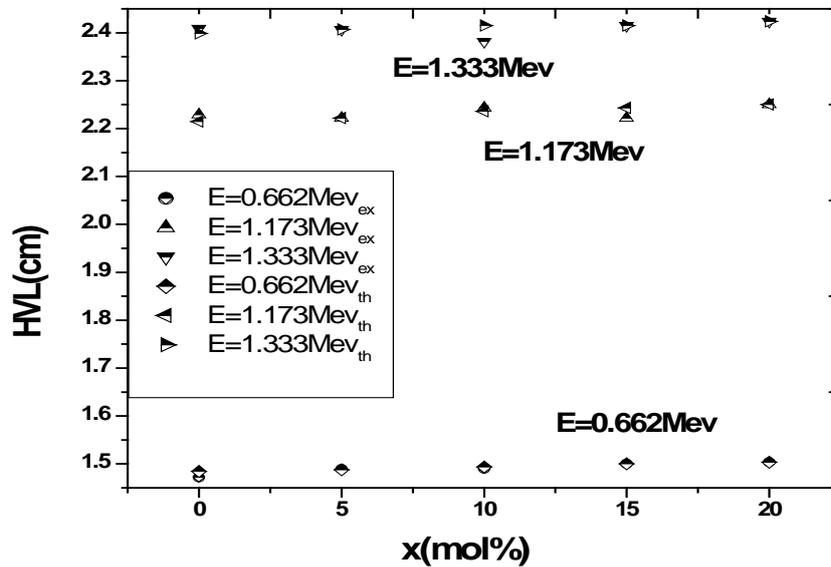


Figure 3. HVL of glass samples for different energies

### 3.4. The Removal Cross-section ( $\Sigma R$ )<sub>C</sub> of Neutron

MERCFSF - N is a computer program used to calculate the fast neutron's effective removal macroscopic cross-section  $\Sigma R$  ( $\text{cm}^{-1}$ ) for homogeneous mixtures [10]. Figure 4 shows the mass removal cross-sections  $\Sigma R$  as a function of  $\text{LiO}_2$  concentration. The calculated values for mass removal cross-sections  $\Sigma R/\rho$  show that the sample contained 5  $\text{LiO}_2$  has the largest removal cross-section and the sample containing no  $\text{LiO}_2$  has the lowest one as shown in Figure 4. These results can be attributed that 5

mol %  $\text{LiO}_2$  helped more collision and elastic scattering of neutrons by boron, also the mass removal cross-section of  $\text{LiO}_2$  is higher than the mass removal cross-section of  $\text{B}_2\text{O}_3$  as well as the increase in the value of the total molar mass of the glass on increasing  $\text{LiO}_2$  mole fraction on expense of  $\text{B}_2\text{O}_3$ . Therefore, the addition of small amount of  $\text{LiO}_2$  improves the removal cross-section values as will be proved from the structural properties (density) of these glasses. By comparing these results to those of the other glass system [10], the present glass samples are good attenuator for fast neutron than others.

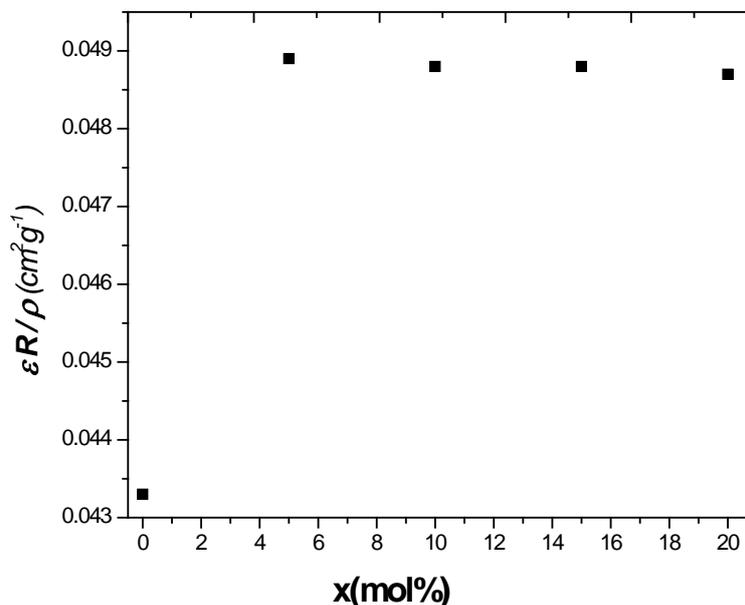


Figure 4. Mass removal cross-sections  $\Sigma R/\rho$  ( $\text{cm}^2/\text{g}$ ) for glass samples

## 4. Conclusion

Lead oxide played a role in attenuating  $\gamma$ -rays. Addition of small amount of  $\text{Li}_2\text{O}$  on the expense of  $\text{B}_2\text{O}_3$  improves the removal cross-section for fast neutrons. The composition with 5 mole %  $\text{Li}_2\text{O}$  is the most efficient one for absorbing fast neutrons. The results in general indicate that the:  $x \text{Li}_2\text{O} - (50-x) \text{B}_2\text{O}_3 - 40\text{PbO} - 10\text{P}_2\text{O}_5$  mole % is very suitable for usage as shielding materials.

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