# CHAPTER 1 INTRODUCTION

## 1.1 Background

By the extensive use of radioactive isotopes in various fields such as industry, medicine and agriculture, the radiation shielding has become an important subject due to required proper precautions to avoid from the radiation hazards [1]. For the radiation shielding purposes, there is away a need to develop material which can be used under harsh conditions of nuclear radiation exposure and can act as shielding materials [2].

There are some basic principles for radiation protection (e.g. shielding). Shielding is generally preferred due to its efficiency in intrinsically safe working conditions, whereas reliance on distance and time of exposure involves continuous administrative control over workers. The type and amount of shielding required depend on the type of radiation, the activity of radiation source and the dose rate that is acceptable for outside the shielding material. However, there are other factors for choice of shielding material such as their cost and weight. An effective shield will cause a large energy loss in a small penetration distance without emission of more hazardous radiation. Furthermore, the good shielding materials should have high absorption cross-section for radiation and at the same time irradiation effects on its mechanical and optical properties should be small [3].

Concrete is the most commonly used shield material as it is inexpensive and adaptable for any construction design. There are however many drawbacks associated with the usage 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. Another drawback is the loss of water when concrete becomes hot by absorption of energy from radiation. Another drawback is that concretes are opaque to visible light and thus it is difficult to see through the concrete-based shield. Moreover, with increasing use of gamma-ray isotopes in industry, medicine and agriculture, it is an important task to develop better radiation shielding materials in terms of size requirements and transparency to visible light. 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 [4-5].

The study of the fundamentals of radiation interactions with materials has become concerned. Data on the attenuation coefficient of X-rays and gamma-rays in matter is required for many scientific, engineering and medical applications. Gamma-rays and X-rays attenuations have been studied for biological materials [6-11], elements [12-15], alloys [16-19] and compounds [4, 20-29]. Most of the previous measurements of attenuation coefficients and related shielding parameters have been performed on the materials in both amorphous and crystalline form [30-32], using various techniques.

The study of the absorption of gamma radiations in materials has been an important subject in the field of radiation physics and is potentially useful in the development of semi-empirical formulations of high accuracy. In order to make used of the fact that scattering and absorption of gamma radiation are related to the density and effective atomic number of the materials, knowledge of the mass attenuation of the materials is essential [33]. From the mass attenuation coefficient, a number of related parameters can be derived, such as photon mean free path, total interaction cross-section, atomic cross-section, electronics cross-section, effective atomic number and effective electron density [34].

Data on absorption of X-rays and gamma-rays are required for many scientific, engineering and medical applications. In 1982, Hubbell have been published the tabulation of mass attenuation coefficient and the energy-absorption coefficients for 40 elements and 45 mixtures and compound over the energy range from 1 keV to 20 MeV. These tables, although widely used, should now be replaced by Hubbell and Seltzer [35], tabulation for all element ($Z$ = 1-92) and 48 additional substances of dosimetric interest. A convenient alternative to manual calculations, using tabulated data, is to generate attenuation data as needed, using a computer. For this purpose, Berger and Hubbell have been developed XCOM for calculating mass attenuation coefficients or photon interaction cross-sections for any element, compound or mixture at energy from 1 keV to 100 GeV [36]. Recently, XCOM was transformed to the Windows operating system by Gerward et al. [37-38], and called WinXCom.

$B_2O_3$ and borate glasses have been widely investigated, although their technological application has been mostly in combination with $SiO_2$. $B_2O_3$ can be considered as having the highest glass formation tendency because molten $B_2O_3$ does not crystallize by itself even when cooled at the slowest rate. $B_2O_3$ crystallizes only under the pressure [39].

The structure of lead borate glasses has attracted the attention in the past several years because of its technological and industrial interests for their use in enamels, photonics, and optoelectronic applications. This type of glass has some interesting features such as low melting temperature, impressive wide glass formation region, high resistance against devitrification, high refractive index and good radiation shielding for gamma-rays. The latter is due to the naturally stable boron isotope that acts as a good absorber for thermal neutrons. Moreover, PbO can enter the glass network both as a network modifier and also as a network former [40-41]. However, the study of the optical and physical properties of the PbO in borate glasses has been paid little attention.

## 1.2 Motivation

Nowadays lead glass has been usually used as gamma radiation shielding materials. Enhancing radiation shielding capabilities of this material is an important issue. The purpose of this research is to explain the shielding behavior of PbO-$B_2O_3$. Therefore, mass attenuation coefficients, effective atomic numbers and effective electron densities were investigated. In addition, the physical and optical properties (e.g. density, molar volume and optical basicity) were then investigated.

## 1.3 Objective

The objectives of this dissertation are the following

1.3.1 To prepare the $PbO$-$B_2O_3$ glass system.

1.3.2 To investigate the effective atomic numbers, electron densities and some basic radiation shielding parameters (e.g. half value layer) of prepared glass samples at 662 keV.

1.3.3 To characterize the physical and optical properties of prepared glass samples.

## 1.4 Literature Reviews

Hubbell, J.H. [35] published tables of mass attenuation coefficients and the mass energy absorption coefficients for 40 elements (ranging from hydrogen to uranium) and 45 mixtures and compounds over the energy range from 1 keV to 20 MeV. These tables, although widely used, should now be replaced by the Hubbell and Seltzer [36] tabulation for all elements ($Z$ = 1-92) and 48 additional substances of dosimetric interest.

Gerward, L. et al. [37-38] developed a Windows version of XCOM, the well-known program for calculating X-ray and gamma-ray attenuation coefficients and interaction cross sections. The new program is called WinXCom, has an improved user interface.

Singh, N. et al. [42] measured the gamma-ray mass attenuation coefficients in experimentally and calculated theoretically for $PbO$-$B_2O_3$ and $Bi_2O_3$-$PbO$-$B_2O_3$ glass systems using narrow beam transmission method. These values have been used to calculate the radiation shielding properties.

Singh, N. et al. [2] studied the $PbO$-$BaO$-$B_2O_3$ glass system in terms of molar mass, mass attenuation coefficient and half value layer parameters by using gamma-ray at 511 keV, 662 keV and 1274 keV photon energies.

Singh, K.J. et al. [43] determined the gamma-ray attenuation coefficients using a narrow beam transmission method for the $x$PbO(1-$x$) : $SiO_2$ ($x = 0.45$-$0.70$) glass system at 662, 1173 and 1332 keV photon energies. The molar volume, FTIR and acoustic investigations have been used to study the structural properties of the prepared glass system.

Singh, H. et al. [4] determined the values of gamma-ray mass-attenuation coefficient, the photon mean free path (*MFP*), the effective atomic number and the effective electron density for $x\mathrm{ZnO} \cdot 2x\mathrm{PbO} \cdot (1\text{-}3x)\mathrm{B_2O_3}$ ($x$ = 0.1-0.26) glasses at photon energies 511, 662, 1173 and 1332 keV and compared with theoretical data.

Singh, H. et al. [5] determined total mass attenuation coefficients, mean free paths (*MFP*), half-value (*HVT*) and tenth-value (*TVT*) thicknesses of Portland cement and three mixtures have been calculated in function of the energy from 1 keV to 100 GeV.

Singh, K. et al. [26] studied the mass attenuation coefficients, effective atomic numbers and effective electron densities experimentally for the glass system $x\mathrm{CaO}$-$(0.3\text{-}x)\mathrm{SrO}$-$0.7\mathrm{B_2O_3}$ at photon energies 511, 662, 1173, and 1332 keV. In addition, the molar volume of the glasses has been derived from density measurements, and the excess volume has been determined as a function of composition.

Khanna, A. et al. [20] measured the linear attenuation coefficients ($\mu$) and mass attenuation coefficients ($\mu/\rho$) of glasses in three systems: $x$PbO(1-$x$)$B_2O_3$, 0.25PbO $\cdot x$CdO(0.75-$x$)$B_2O_3$ and $x Bi_2O_3(1-x)B_2O_3$ at 662 keV.

Jackson, D.F. and Hawkes, D.J. [44] studied the X-ray attenuation in samples of pure elements and mixtures of elements. The emphasis is on the energy range 30-150 keV although the energy regions 10-30 and 150-1000 keV are also discussed.

Singh, K. et al. [21] studied the effective atomic numbers and mass attenuation coefficients of some different compounds for total and partial photon interactions in the energy range $10^{-2}$-$10^{5}$ MeV. The effective atomic numbers and mass attenuation coefficients have also been determined experimentally in the energy range 123-1132 keV by a transmission method.

Manohara, S.R. et al. [6] calculated the effective atomic numbers and electron densities of essential amino acids histidine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine for total and partial photon interactions by the direct method in the wide energy range of 1 keV-100 GeV using WinXCOM.

Icelli, O. et al. [9] determined variation of the mass attenuation coefficients of $H_3BO_3$ according to percentage increasing concentration of $H_3BO_3$ by using an extremely narrow-collimated-beam transmission method in the energy range 15.746-40.930 keV with an X-ray transmission method. The characteristic $K_\alpha$ and $K_\beta$ X-rays of the different elements (Zr, Mo, Ag, In, Sb, Ba and Pr) passed through boric acid was detected with a high-resolution Si(Li) detector.

Gowda, S. et al. [11] calculated the effective atomic numbers and electron densities of the amino acids glycine, alanine, serine, valine, threonine, leucine, isoleucine, aspartic acid, lysine, glutamic acid, histidine, phenylalanine, arginine, tyrosine, tryptophane and the sugars arabinose, ribose, glucose, galactose, mannose, fructose, rhamnose, maltose, melibiose, melezitose and raffinose at the energies 30.8, 35.0, 81.0, 145, 276.4, 302.9, 356, 383.9, 661.6, 1173 and 1332.5 keV by using the measured total attenuation cross-sections.

Gahlot, P.S. et al. [45] studied the heavy metal based oxide glasses having composition $x Bi_2O_3 \cdot (0.30-x) PbO \cdot 0.70 B_2O_3$ ($0.00 \leq x \leq 0.15$, mol%) containing 2.0 mol% of $V_2O_5$. Electron paramagnetic resonance (EPR), optical spectra and dc conductivity of these glasses have been studied.

Reddy, R. R. et al. [46] estimated the average electronic oxide polarizability ($\alpha_o^{2-}$) and optical basicity ($\Lambda$) of numerous simple oxides on the basis of different properties of oxides: average electronegativity ($\chi_{av}$) and energy gap ($E_g$).

Dimitrov V., and Komatsu T. [47] estimated the average electronic polarizability of the oxide ion $\alpha_O^{2-}(n_o)$ of numerous binary oxide glasses (phosphate, borate, silicate, germanate, tellurite and titanate) on the basis of the refractive index.

Dimitrov V., and Komatsu T. [48] classified the binary oxide by taking into account the refractive index–based oxide ion polarizability $\alpha_{O}^{2-}(n_o)$, optical basicity $\Lambda(n_0)$, metallization criterion $M(n_0)$, interaction parameter $A(n_0)$, and ion's effective charges as well as O1s and metal binding energies determined by X-Rays Photoelectron Spectroscopy (XPS).

Dimitrov V., and Komatsu T. [49] proposed the simple oxide classification on the basis of correlation between electronic polarizabilities of the ions and their binding energies determined by XPS.

**Table 1.1** Literature Reviews.

| Glasses/Materials | Properties | | | | | | |
|---|---|---|---|---|---|---|---|
| | Radiation Shielding | Physical | Structural | Optical | Electrical | etc. | References |
| 40 Elements, 45 Mixture and Compound | • Mass attenuation coefficients<br>• Mass energy absorption coefficients | - | - | - | - | - | [35] |
| All Elements (Z=1-92), 48 additional substances of dosimetric interest | • Mass attenuation coefficients<br>• Mass energy absorption coefficients | - | - | - | - | - | [36] |
| $PbO$-$B_2O_3$, $Bi_2O_3$-$PbO$-$B_2O_3$ and Shielding materials | • Mass attenuation coefficients<br>• Half value layer | • Density<br>• Molar volume | - | - | - | - | [42] |
| $PbO$-$BaO$-$B_2O_3$ and Radiation shielding concretes | • Mass attenuation coefficients<br>• Half value layer | • Density<br>• Molar volume<br>• Thickness<br>• Excess volume | - | - | - | - | [2] |
| $x$PbO(1-$x$) : $SiO_2$ ($x = 0.45 - 0.70$) | • Mass attenuation coefficients<br>• Half value layer | • Density<br>• Molar volume<br>• Excess volume | • XRD<br>• FTIR | - | - | - | [43] |
| $x$ZnO-2$x$PbO-(1-$x$)$B_2O_3$ ($x = 0.1$-$0.26$) | • Mass attenuation coefficients<br>• Mean free path<br>• Effective atomic numbers<br>• Effective electron densities | • Density<br>• Molar volume<br>• Thickness | - | - | - | - | [4] |

| Glasses/Materials | Properties | | | | | | |
|---|---|---|---|---|---|---|---|
| | Radiation Shielding | Physical | Structural | Optical | Electrical | etc. | References |
| Building materials | • Mass attenuation coefficients<br>• Half value layer<br>• Tenth value layer<br>• Mean free path | - | - | - | - | - | [5] |
| $x$CaO-(0.3-$x$)SrO-0.7$B_2O_3$ | • Mass attenuation coefficients<br>• Effective atomic numbers<br>• Effective electron densities | • Density<br>• Molar volume<br>• Thickness<br>• Excess volume | - | - | - | - | [26] |
| $x$PbO(1-$x$)$B_2O_3$, 0.25PbO-$x$CdO (0.75-$x$)$B_2O_3$, $x$$Bi_2O_3$(1-$x$)$B_2O_3$ and Standard shielding materials | • Linear attenuation coefficients<br>• Mass attenuation coefficients<br>• absorption cross sections per atom | • Density<br>• Thickness | - | - | - | - | [20] |
| Compounds | • Total and partial interaction<br>• Mass attenuation coefficients<br>• Effective atomic numbers | - | - | - | - | - | [21] |

| Glasses/Materials | Properties | | | | | | |
|---|---|---|---|---|---|---|---|
| | Radiation Shielding | Physical | Structural | Optical | Electrical | etc. | References |
| Essential amino acids | • Mass attenuation coefficients<br>• Effective atomic numbers<br>• Effective electron density | - | - | - | - | - | [6] |
| Boric acid | • Mass attenuation coefficients | - | - | - | - | - | [9] |
| Amino acids and Sugars | • Mass attenuation coefficients<br>• Effective atomic numbers<br>• Effective electron densities | - | - | - | - | - | [11] |
| $x\text{Bi}_2\text{O}_3$-$(0.30-x)\text{PbO}$-$0.70\text{B}_2\text{O}_3$ | - | • Density<br>• Thickness | - | • UV-Visible<br>• Optical basicity<br>• Cutoff wavelength<br>• Optical band gap | • DC conductivity<br>• Activation energy | • EPR | [45] |
| Simple oxides | - | - | - | • Electronic polarizability<br>• Oxide ion polarizability<br>• Optical basicity<br>• Energy band gap | - | - | [46] |

| Glasses/Materials | Properties | | | | | | |
|---|---|---|---|---|---|---|---|
| | Radiation Shielding | Physical | Structural | Optical | Electrical | etc. | References |
| Oxide glasses | - | - | - | • Linear refractive index<br>• Electronic polarizability<br>• Oxide ion polarizability<br>• Cation polarizability<br>• Optical basicity<br>• Energy band gap<br>• Molar refraction<br>• Non-linear optical susceptibility | - | - | [47] |
| Oxide glasses | - | - | - | • Linear refractive index<br>• Oxide ion polarizability<br>• Optical basicity<br>• Molar refraction<br>• O1s binding energy<br>• Interaction parameter<br>• Metallization criterion | - | - | [48] |

| Glasses/Materials | Properties | | | | | | |
|---|---|---|---|---|---|---|---|
| | Radiation Shielding | Physical | Structural | Optical | Electrical | etc. | References |
| Simple oxides | - | - | - | • Molar refraction<br>• Molar polarizability<br>• Oxide ion polarizability<br>• O1s binding energy<br>• Optical basicity<br>• Linear refractive index<br>• Energy gap | - | - | [49] |