PHOTON INTERACTION PARAMETERS INVESTIGATIONS FOR LEAD BOROPHOPHATE GLASSES AT 59.54 KEV INCIDENT PHOTON ENERGY

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Abstract

Total Mass Attenuation Coefficient (μm), total Photon Interaction Cross-Section, Effective Atomic Numbers (Zeff) and Electron Densities (Ne) of xPbO–(40–x)B2O3–40P2O5–10Na2O-9.6ZnO-0.2Sm2O3-0.2Gd2O3 glass system (x = 10, 15, 20, 25, 30, 35) have been investigated at 59.54 keV energy photon emitted by 100 mCi241Am point source employing narrow beam transmission geometry. Experimental results have been compared with theoretically calculated values using WinXCOM. A good agreement has been observed between experimental and theoretical values within experimental uncertainties. Among prepared glass samples, the glass sample with maximum contribution of PbO has maximum value of μm and Zeff.
Keywords: Borophosphate Glasses, Mass Attenuation Coefficient, Effective Atomic Number, Electron Densitiesolution Neural network (CNN), image acquisition, image pre-processing, Feature extraction, leaf classification.

Introduction

Natural glass exists from the beginning of the formation of Earth, formed when certain types of rocks melt due to the volcanic explosion, lightning strikes or the collision of meteorites. Modern glass is a resourceful material that is commercially available over a wide range ofcompositions and can be fabricated in huge varieties.The advantages of glass are the ease to fabricate, homogeneity and transparency to various radiations. Glasses also show radiation shielding property and this property can be further improved by the addition of high atomic number element oxide in the glass composition. In place of concrete, the glass materials are also considered as good substitute for shielding purpose [1].Glasses can also have potential application in developing materials for detecting gamma rays through down conversion of energy[2]. Detection of high energy gamma radiations find applications in scientific research such as in high energy physics, astrophysics, radiochemistry, nuclear and medical research as well as in national defense and homeland security.

In dealing with mixture of molecules, such as composites and glasses etc., it is convenient to describethe mixture by an effective atomic number (Zeff). It is a parameter dependent on incident photon energy and it points out that at a given energy, photons interacts with a composite material in a similar manner as a single element of atomic number correspondent to that composite material.The mass attenuation coefficient (μm) and Zeff is an essential quantity fordetermining the penetration of gamma-ray photons in matter. Along withZeff, the effectiveelectron density (Ne) is also a suitableparameter in designing radiation shielding,computing absorbed dose, energy absorption and build-up factor which represent radiation interaction with matter[3]. Various investigations have been made to study the shielding properties of glass systems [4-10]. Koudelkaet. al[11]has investigated the structure and properties of zinc and lead borophosphate glasses. With the application of Raman spectroscopy and infrared spectroscopy some structural studies were also made by them. A.M.A.Mostafa et al. [12] has investigated WO3 based glass system in composition (100-x)[0.1B2O3-0.4P2O5-0.5PbO]-xWO3 where x = 10, 20, 30, 40, 50 and 60 mol% for gamma ray shielding properties with NaI(Tl) scintillation detector. In recent years glasses doped with rare-earth ions have attracted much attention because of their many technological applications. These glass systems have potential applications in the development of new tunable solid state lasers, luminescent solar energy concentrators and fiber optic communication devices.

The present study is made to investigate the µm, Zeff and Ne for photon interactions of xPbO–(40–x)B2O3–40P2O5–10Na2O-9.6ZnO-0.2Sm2O3-0.2Gd2O3 glass system (x = 10,15, 20, 25, 30, 35) at the incident photon energy 59.54 keV and to further check its radiation shielding properties. Considering the advantage of borophosphate glasses, an attempt has been made to check leadborophosphate glasses doped with Sm+3 and Gd+3 in different composition of B2O3, PbOand constant weight fraction of P2O5, Gd2O3 and Sm2O3 and to explore its feasibility as gamma ray shielding material.

Theoretical Consideration

A mass attenuation coefficient (µm) measures the number of photons interacting with the associated material. The µm values of the selected glass samples were generated in the energy region from 1 keV to 100 GeV using WinXCom [13]energy grid based on the mixture rule as given by Equation 1. The WinXCom program provides total cross section and attenuation coefficients as well as partial cross sections for various interaction processes for about 100 elements:

$$\mu_m = \frac{\mu}{\rho} = \sum_i w_i \left(\frac{\mu}{\rho}\right)_i (cm^2/g) \qquad 1.$$

where is the weight proportion of the ith constituent element, (µ/ρ)i is mass attenuation coefficient of constituent element. For glasses, the mixture rule is valid with the assumption that the effects of molecular binding and the chemical and crystalline environment are negligible.

Total photon interaction cross-section of sample is obtained as:

$$\sigma_t = \frac{M}{N_a} (\mu_m)_{glass} (barn/molecule) \qquad 2.$$

where M is molecular weight of sample and Na is Avogadro's number.

The total atomic cross-section aσ is related to tσas:

$$\sigma_a = \frac{\sigma_t}{\sum_i n_i} (barn/atom) \qquad 3.$$

where $\sum_i n_i$ is total number of atoms in a molecule.

The average electronic cross-section is calculated as:

$$\sigma_e = \frac{1}{N_a} \sum_i \frac{f_i A_i}{Z_i} (\mu_m)_{glass} (barn/electron) \qquad 4.$$

$$Z_{eff} = \frac{\sigma_a}{\sigma_e} (unitless) \qquad 5.$$

The electron density (number of electron per unit mass) is obtained as:

$$N_e = \frac{\mu_m}{\sigma_e} (e/g) \qquad 6.$$

Glass Sample Preparation

All the samples are prepared by conventional Melt Quench Technique. For the present studyglass systemxPbO–(40–x) B2O3 –40P2O5–10Na 2O-9.6 ZnO-0.2Sm2O3-0.2Gd2O3 (x=10,15, 20, 25, 30, 35), the research grade chemical powders in required amounts were mixed in mortar and pestle. The mixture is then transferred to silica crucible and placed in muffle electric furnace to melt them for an hour at 8500C. The increment of temperature of the furnace was in the steps of 50°C. The molten material was then poured in a preheated (at 3000C) graphite mould to get the glass samples. After 20 mins of pouring the sample, the annealing furnace was turned off. To protect the samples from thermal cracking the mould was kept inside the furnace for 24 hours. Prepared glass samples were grinded by using grinding machine. The flat surfaces were obtained and the samples were polished by using Ceric Oxide (CeO2) as fining agent. The chemical composition and the density of the samples are given in Table 1.

Table 1. Chemical composition by weight, density and thickness of sample									
Sample Name	Composition (mole fraction)							Density ρ (g/cm3)	Thickness (cm)
	PbO	B2O3	P2O5	ZnO	Na2O	Sm2O3	Gd2O3		
P1	10	30	40	9.6	10	0.2	0.2	3.5901	0.658
P2	15	25	40	9.6	10	0.2	0.2	3.6327	0.693
P3	20	20	40	9.6	10	0.2	0.2	3.6357	0.755
P4	25	15	40	9.6	10	0.2	0.2	4.0866	0.913
P5	30	10	40	9.6	10	0.2	0.2	4.3504	0.918
P6	35	5	40	9.6	10	0.2	0.2	4.6597	0.986

The density of the prepared glass samples at room temperature was determined by using simple Archimedes method using benzene as immersing liquid (ρ_o = 0.876 g/cm3). The density (ρ) of glass samples was calculated by using relation as:

$$\rho = \rho_o \frac{W_{air}}{W_{air} - W_1} \quad 7.$$

where ρ_o is the density of the benzene, $_{air}W$ is the sample weight in air and $_lW$ is the sample weight in benzene.

Experimental Details

First linear attenuation coefficients of aforesaid glass sample systems were obtained by using narrow beam transmission geometry and 100 mCi241Am (59.54 keV) point source along with CANBERRA made Si(Li) detector. The spectrum is analyzed with the help of window based software Genie 2000. The detector was properly shielded to reduce the background to low level. In order to minimize the multiple scattering of the radiation, collimationsof decreasing order are used in both measurements. The geometrical arrangement used for present measurement is shown in Figure. 1. Incidentand transmitted beam intensityfor each sample were measured for sufficiently large fixed preset time. Three data sets for each target are recorded along with their respective backgrounds over a time interval of 3600 seconds each. Then the weighted averages of these data are taken in each case to improve the statistics of the data better than 1% at the studied energy. Reproducibility and Stability of the method used was tested before and after each run. To determine the mass attenuation coefficient value, the obtained linear attenuation coefficient of a particular glass sample was divided by its respective density.

The corrections due to the response functions of Si(Li) detector are applied to the measured spectrum. The errors are due to the statistics of the data, geometrical full energy peak efficiency of detector at particular energy and area under the photo-peak. The overall error in the experimental values of various parameters is within 3.5%.

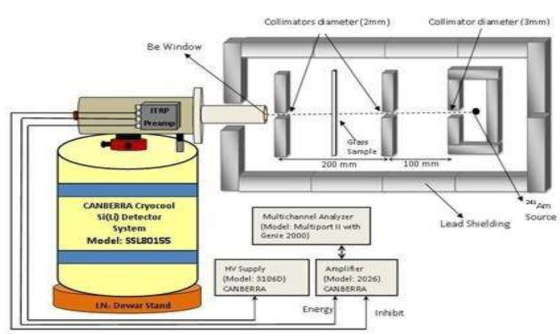

Figure 1: Experimental setup

Systemmeasured at photon energy 59.54 keV together with the theoretical values calculated using mixture rule from WinXCOM are given in Table 2. It is evident from the table that the measured values of these parameters are in good agreement with those obtained theoretically. Experimental as well as theoretical values of effective atomic numberare also tabulated in Table 2. The theoretical and experimentally measured values of the effective atomic number (Zeff) are given in Table 2. It has been observed from Table 2 that Zeffof glass samples are found to lie within range of 7.171-18.223. Results for the effective numbers of electrons per unit mass, i.e., electron density (Ne), calculated by making use of the values of Zeff, are given in Table 2. It is observed that with increase inPbO content in the glass samples the values of μm, Zeff and Neincrease. It is evident that the sample with higher PbO content acts as a better shielding material for gamma radiations.

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