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Gamma Ray Attenuation Parameters of Some Boro-Silicate Glasses Doped Mixed Heavy Metal ions

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ABSTRACT: The attenuation of gamma-ray radiation depends mainly on the energy of the incident gamma photon, the effective atomic number, density of the elements in the shielding material and the thickness of such shield. However, in this work, mass and linear attenuation coefficients, effective atomic number and electron density, mean free paths, half value layer and 10th value layer of some barium-bismuth-boro-silicate glasses were obtained at gamma-ray photon energies of 0.662, 1.173 and 1.332 MeV, by using Win-XCOM computer program. The obtained data were then compared with the experimental data. The obtained theoretical results were found in good agreement with these obtained experimentally. According to the obtained results, it can be stated that, Boro-silicate glasses containing mixed heavy metal oxides (BaO and Bi_2O_3) appeared to be transparent and have good gamma-ray shielding properties. But the best glass sample that can act as good attenuator is that containing 25 mol% Bi_2O_3, at low gamma-ray energy photons.

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1. INTRODUCTION

Glasses appeared now of special interest because they are optically transparent and easy manufactured. Therefore gamma-ray attenuation parameters have been thoroughly investigated for various types of glasses specially those containing heavy metal ions (HMIs) [*(Abdel_Ghany et al. 2015),(Bagheri et al., 2016), (Kaewjaeng et al.,2012), (Chahine et al., 2004), (Kirdsiri et al., 2011)]*. Among various glass types, boro-silicate glasses represent an interesting glass family in the field of glass science. These glasses are characterized by their low thermal expansion coefficients, resistance to thermal shock and ability for transmitting visible light. The addition of some HMIs (as bismuth or barium), promotes these gamma ray shielding properties [*(Zoulfakar et al., 2017), Chanthima et al., 2013), (Kaur et al., 2016)*]. According to a quick review of literatures, it is easy to observe that many articles have been published concerning with the study of the attenuation parameters of various glasses containing single HMI, but what about the attenuation parameters if two different HMIs are introduced in a glass network?.

However, the effect introducing two mixed HMIs (bismuth & barium) on the structure and the nuclear shielding parameters of some borosilicate glasses will be thoroughly investigated. The molecular composition of the supposed glasses are [20% SiO_2 + 54% B_2O_3 +1%NiO + x% Bi_2O_3 + (25-x) BaO], x= 5, 10, 15, 20 and 25. Win-XCom program was applied at different gamma rays energies to determine of radiation shielding parameters of the supposed glass system. The obtained results were compared with the available experimental data to achieve asuitable shielding glass and the most appropriate composition required for a particular application.

2. EXPERIMENTAL WORK

Glasses of the molecular composition, [20% SiO_2 + 54% B_2O_3 +1%NiO + x% Bi_2O_3 + (25-x) BaO], x= 5, 10, 15, 20 and 25, have been prepared by the melt quenching method. Pure grade silicon dioxide (SiO_2), boric acid (H_3BO_3), barium carbonate ($BaCO_3$), nickel oxide (NiO) and bismuth oxide (BiO_3) were used to prepare the glass batches to yield 30 g glass samples. The batches were mixed and ground well in an agate mortar. They were then placed in porcelain crucibles and were melted in an electric muffle furnace at 1200 ^oC for 2 hrs. Melts were stirred several times during melting, in order to obtain homogenous glass samples. Then they were casted onto a copper molds to obtain the desired solid samples.

X-Ray diffraction patterns were recorded at room temperature with 2q between $4^o$and 90^o, using a SHIMADZU 6000,X-Ray Diffractometer, outfitted with copper target (λ = 1.542 A^0), operating at 40 kV and 30mA.

Density measurements were carried out applying Archimedes's principle, byusing CCl_4 as an emersion liquid and an electric balance with accuracy of 4-decimal digits. The molar volume values were then calculated by using the obtained density values.

Attenuation coefficients of the prepared glassesb were measured in narrow beam transmission geometry by using NaI (TI) crystal detector with energy resolution of 12.5% at 662 keV, in conjunction with multi-channel analyzer (MCA). ^{60}Co and ^{137}Cs radioactive sources were used to radiate different gamma-ray photon energies. The intensities of the incident and transmitted photons of the used gamma ray energies were measured on the MCA for a fixedtime by selecting a symmetrical narrow region with respect to the centroid of the photon peak (Ahmed et al., 2015).

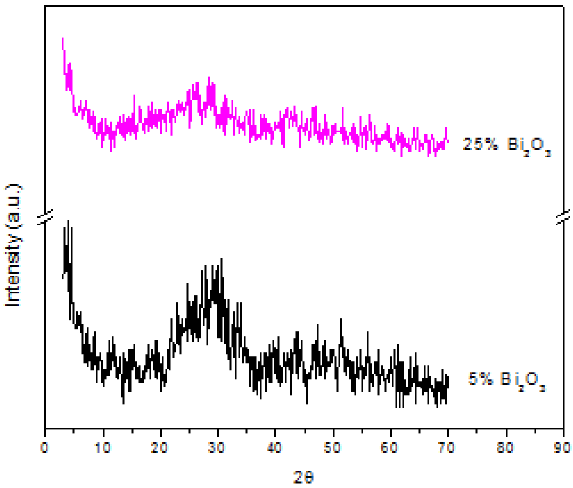
3. RESULTS AND DISCUSSION

3. 1. X-Ray diffraction

The samples under study were examined visually, where they all appeared to be transparent and free of cracks, air bubbles and inhomogeneity, that is they appeared in pure amorphous state. In spite of this, XRD analysis was applied here to confirm the amorphous nature of the prepared samples. However, Fig. 1 shows the XRD patterns of the samples in which x=5 and 25 Bi_2O_3 respectively, as representative patterns. It is seen that, there are only humps in between 2q = 20 and 35^o, with no any sharp peaks (due to any crystalline phase) in all samples. Doubtless, this confirms directly the amorphous nature and randomness character (glassy phase) of all the studied samples.

Fig. 1: XRD of the glass samples containing 5and 25 mol% as representative curves.

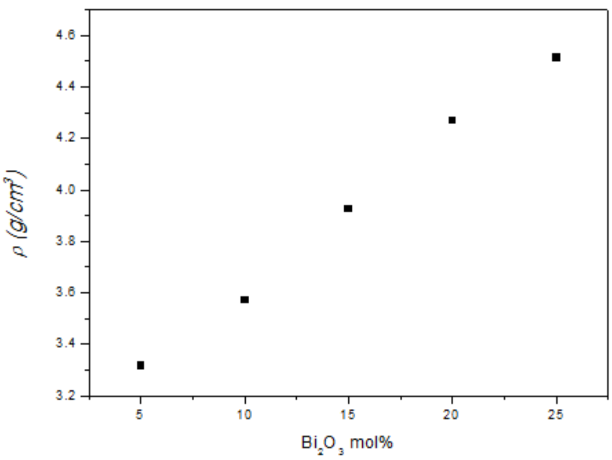
3. 2. Density and molar volume



The density (ρ) of the studied glasses was measured using Archimedes's principle, and the obtained values are depicted in Fig. 2 as a function of Bi2O3. It is observed that, with the increase of Bi2O3 content, the density show gradual linear increase. Such increase may be due to the replacement of BaO (of lighter molecular weight (153.34 g/mol)) by Bi2O3 (of heavier molecular weight (465.96 g/mol)) in the glass network which leads logically to increase the density of the studied glasses.

Fig. 2: The change of density versus Bi_2O_3 content.

Thereafter, by the aid of the obtained density



values, the molar volume (V_m) values were calculated and its variation is exhibited in Fig. (3) as a function of Bi_2O_3 content.

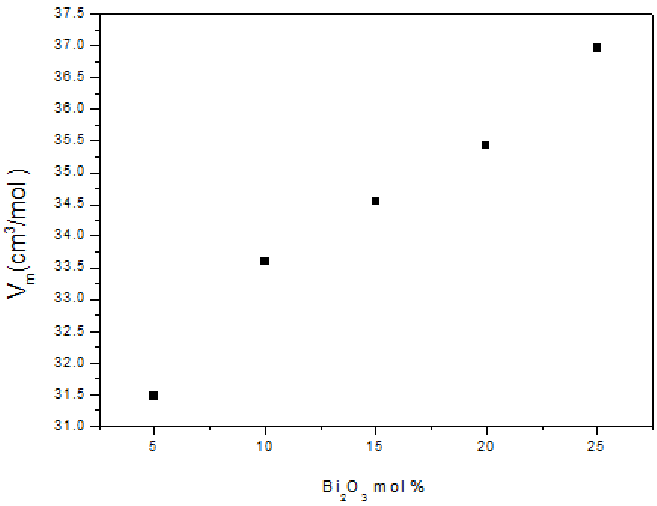


Fig. (3): The change of the molar volume versus Bi_2O_3 content.

The It is observed that as Bi_2O_3 content was gradually increased, V_m shows gradual linear increase. Such increase in the molar volume may be due to the following factors:

- The gradual increase in the number of oxygen anions in the glass network, where one oxygen (BaO) is replaced by three oxygen anions (Bi_2O_3).
- The gradual increase of the positive cations where, only single barium cations is replaced by two bismuth cations. In addition to the differences in their ionic radii of both cations where, the ionic radius of Bi^{+3} equals 1.2 A° while the ionic radius of Ba^{+2} equals 1.35 A°.

The gradual increase of V_m can be taken as evidence for the increase of the number of vacancies in the network.

3.3. Linear and Mass attenuation Coefficients

The linear attenuation coefficient (m_l) values were measured experimentally, while the mass attenuation coefficient (m_m) values were calculated by dividing the linear attenuation coefficient by the density of a sample. Also the linear and mass attenuation coefficient values were calculated theoretically for the gamma-photon energies of interest by using Win-

XCOM program. The variations of both coefficients are depicted in Figs (4 and 5) respectively as a function of Bi_2O_3 content. It is observed from both figures that the values of the linear and mass attenuation coefficient values increased as Bi_2O_3 content was increased. This increase may be due to the high atomic weight of bismuth (Bi=208.98 g/mol) when compared with that of barium (Ba=137.34 g/mol). It is also observed that, such increase is more intense at low gamma-ray energies than at high energies which may be due to the process of photoelectric effect, that is usually preferable with high-atomic-number absorbers and low photons energies.

It can be observed that, both the experimental and the theoretical linear attenuation coefficient values appeared to be approximately coincident.

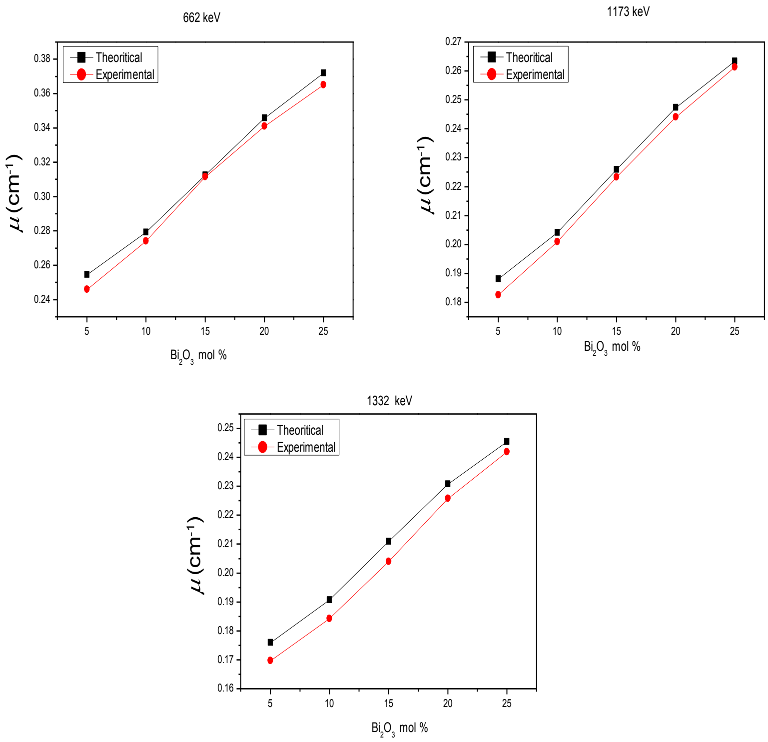


Fig. 4: The change of the linear attenuation coefficient (m_l)at various photon energies versusBi_2O_3 content.

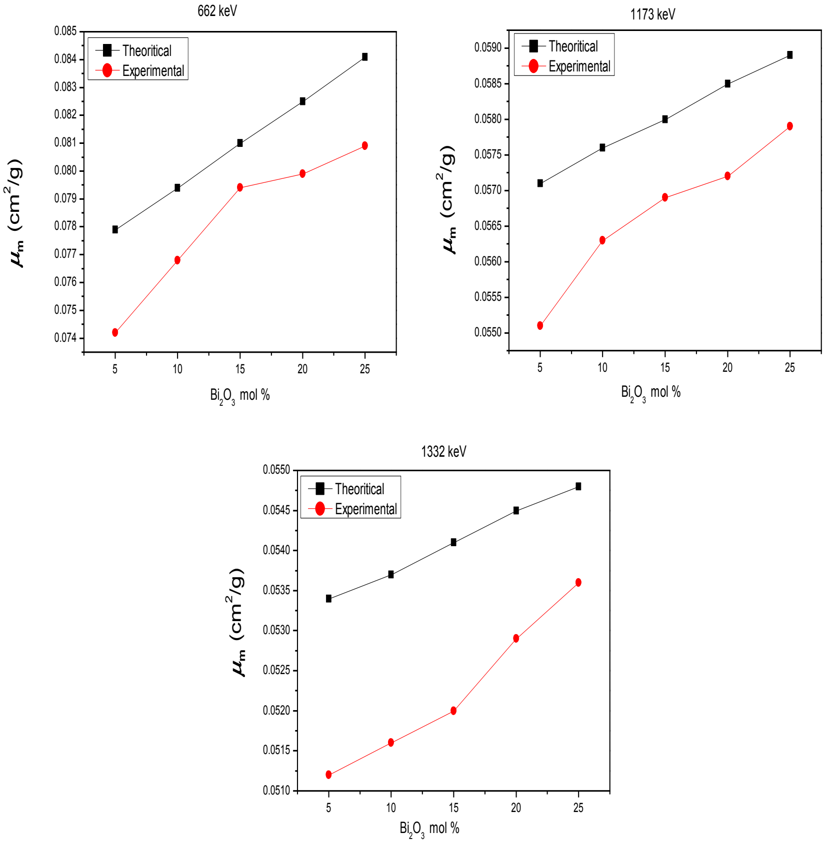


Fig. (5): The change of the mass attenuation coefficient (m_m)at various photon energies versus Bi_2O_3 content.

3. 4. The half value layer (HVL)

The HVL is used to describe the effectiveness of gamma-ray shielding material ***(Manohara et al., 2009)***.The calculated values of HVL are depicted in Fig. (6). It is observed that the obtained HVL decreased with increasing Bi_2O_3 content in the studied glasses. Such decrease of HVL can be attributed to the increase in density and mass attenuation coefficient of the studied glasses with increasing Bi_2O_3 content.

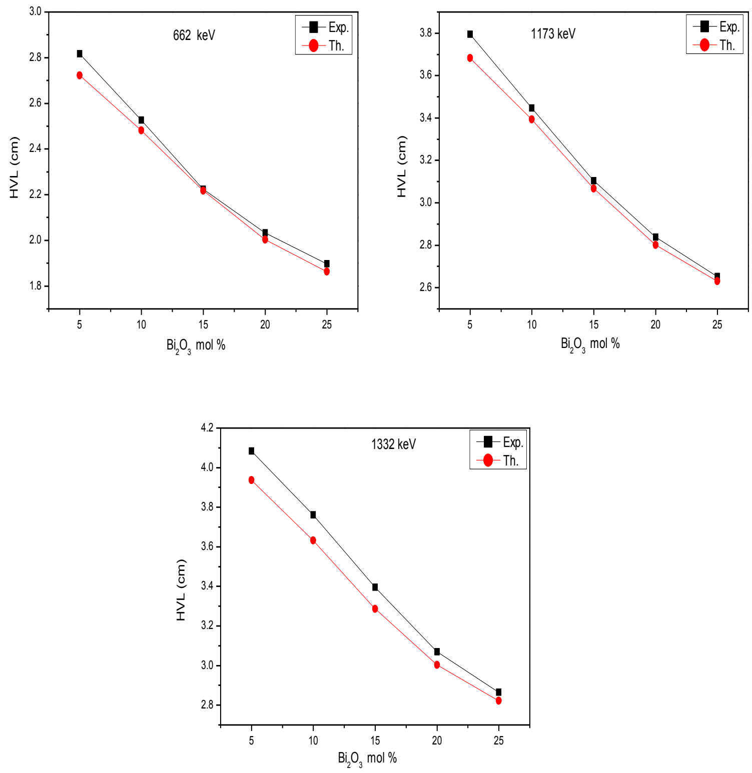


Fig. 6: The change of HVL at various photon energies versus Bi_2O_3 content.

Conclusion

According to the investigated gamma-ray shielding parameters of some barium-bismuth-boro-silicate glasses (glasses under study) at different energies of gamma rays (662 keV, 1,173 keV, and 1,332 keV) using Win-XCOM program and the available experimental measurements it can be concluded that, as Bi_2O_3 was gradually increased.

1- Both the obtained experimental and theoretical results are compared with each other were they show approximately good agreement.

2- The prepared glasses having mixed heavy metal cations can be used as radiation shielding materials. Specially at low gamma-ray photon energies.

3- It was found that the samples with high bismuth oxide content have higher density, consequently higher mass attenuation coefficient and low HVL.

4- The calculated V_m shows also gradual increase due to the difference between the atomic radii of both Bi and Ba as well as due to the gradual increase of oxygen anions in the glass networks.

5- It is concluded also that, the attenuation parameters (m_l &m_m) of a sample increased with Bi_2O_3 content, while they decreased with the increase of gamma-ray photon energy.

6- It is found that, the sample that contains 25 mol% Bi_2O_3 is the best one for attenuating low gamma-ray photon energies.

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