The Gamma Rays Shielding Properties of Barium Phosphate Glasses in Energy Range 1 keV to $10^8$ keV

K. Jarupreedephad$^{a,b}$*, P. Borisut$^{a,b}$, W. Chaiphaksa$^{a,b}$, P. Limkitjaroenporn$^{a,b}$ and J. Kaewkhao$^{a,b}$

$^a$ Physics Program, Faculty of Science and Technology, Nakhon Pathom Rajabhat University, Nakhon Pathom 73000, Thailand
$^b$ Center of Excellence in Glass Technology and Materials Science (CEGM), Nakhon Pathom Rajabhat University, Meuang, Nakhon Pathom, 73000, Thailand

*Corresponding Author: chaipaksa@gmail.com

Abstract. This research aimed to study the gamma ray shielding properties of (100-x)P$_2$O$_5$:xBaO glass systems (where x = 5, 15, 25, 35, 45, 55, 65, 75 mol. %), calculated by WinXcom program. The theoretical values of the mass attenuation coefficient, effective atomic number, and electron density were investigated in the energy range of 1 keV to $10^8$ keV. The partial interactions (photoelectric, coherent scattering, incoherent scattering, and pair production) were studied in this work. The results show the higher gamma ray shielding properties at the higher concentration of barium oxide in the glass formula. Moreover, the half value layer results have been compared with some standard shielding materials at 662 keV for gamma ray.

1. Introduction

Ionizing radiation is harmful to the human body. Radiation shielding can be done by finding a shielding material for attenuation of photon energy [1, 2]. There are many shielding types of shielding material with different pros and cons such as lead is low cost, high density but high toxicity and chemical stability [1], silicone is a flexible material but it is not transparent [3, 4]. Glass material is another radiation shielding because it is transparent and easy to fabricate. The composition can also be modified using techniques and preparation. Considerations for making radiation shielding glass are that they must be clear and dense. Therefore the chemical composition of glass should have a high atomic number and must be colourless to make glass clear.

Many literature review of glass research, such as Ali Erçin Er sundu, M.I. Sayyed, and other people studied the Bi$_2$O$_3$: PbCl$_2$: TeO$_2$ system glass, the result was transparency above 70% with a pale-yellow colour, high density and should add Bi$_2$O$_3$ and PbCl$_2$ to enhance the shielding [5]. M.H.A. Mhareb, Y.S.M. Alajersami and other people studied H$_3$BO$_3$: ZnO: Na$_2$O: BaO glass system. In this studied glass system showed that, when added barium oxide increases density and the addition of zinc increases the resistance to chemical, heat Stability and reduce crystallization [6]. Shams A.M. Issaa, Atif Mossad Alic and other people studied xPbO: (50-x) MoO$_3$: 50V$_2$O$_5$ (25 ≤ x ≤ 45 mol %) glass system, was used instead of lead due to its high toxicity and not transparent. However, glass is a transparent material and has also been added with lead to further reduce its radiation shielding [7]. And Y.S. Rammah, M.S. Al-Buriah, A.S. Abouhaswa studied Bi$_2$O$_3$: BaCO$_3$: Li$_2$O glass system doped with Co$_3$O$_4$, were effective against gamma rays at the energy range 0.01 to 15 MeV. These
borate-based glasses can be used in many ways as a radiation shield [8]. From the above studies, it was found that high-density glass provides good radiation shielding. (100-x)P₂O₅ : xBaO glass systems were an undiscovered glass system, so it is very interesting for development and characterization.

The P₂O₅ is the main component of glass, because high atomic number (Z=15) and low melting point (340 °C) compared to other chemicals used as a primary glass former. BaO is also used as a glass element. Because BaO is clear and has a high atomic number (Z=56), it tends to make high efficiency radiation shielding.

By aimed theory of gamma ray shielding properties investigation of (100-x)P₂O₅ : xBaO glass systems (where x = 5, 15 , 25 , 35 , 45 , 55 , 65 , 75 mol.%), by WinXcom program were studied. The studied parameters of the mass attenuation coefficient, effective atomic number, and electron density were investigated in energy range 1 keV to 10⁸ keV.

2. Related theories

WinXcom program was developed by Berger and Hubbell, was used to calculate the mass attenuation coefficient or photon interaction cross-sections of element, compound or mixture in energy rang 1 keV to 10⁸ keV [9].

2.1. The mass attenuation coefficient (μₚₖₚ)

When gamma rays travel through material it will lose energy. By depending on each material were calculated according to the following equation [10].

\[ \mu_m = \sum w_i (\mu_{i}) \]  

2.2. Effective atomic number (Z_{eff})

Where weight fraction of each element in mixture, (\mu_{i}) is mass attenuation coefficient for individual element in mixture [11].

\[ Z_{eff} = \frac{\sigma_{i,\alpha}}{\sigma_{i,\alpha}} \]  

2.3. the total atomic cross-section (σ_{i,\alpha})

The total atomic cross-section can determine from the values of mass attenuation coefficients by the following relation [12].

\[ \sigma_{i,\alpha} = \frac{\mu_{\alpha}}{N_A \sum (w_i/A_i)} \]  

2.4. The total electronic cross-section(σ_{i,\alpha})

The total electronic cross-section can determine from the values of mass attenuation coefficients by the following relation [13]. Where f, is the number of atoms of element Z, is the atomic number of the element in composites. Where f, is the number of atoms of element Z, is the atomic number of the element in composites [14].

\[ \sigma_{i,\alpha} = \frac{1}{N_A \sum Z_{i} f_{i} A_{i}} \mu_{\alpha} \]
2.5. Electron density ($N_{eff}$)

\[
N_{eff} = \frac{\mu_e}{\sigma_{el}}
\]

3. Results and discussion

The study different composition of barium phosphate glasses systems by the direct method over wide photon energy range from 1 keV to $10^8$ keV using WinXCom program. These data are represented by Fig. 1-5.

3.1. The mass attenuation coefficient

The calculation of barium phosphate glass by WinXcom program the results of mass attenuation coefficient show in fig 1, when the host glass doped barium oxide, the values of mass attenuation coefficient found that discontinuity in the lower energy, this is due to the effect of some element in the glass matrix. The Compton edge were occurred in the energy range of $1 \times 10^{-3}$ MeV (M1, M2, M3 of Barium), $1 \times 10^{-2}$ (K of phosphorus) MeV (K of phosphorus) and $1 \times 10^{-1}$ MeV (L1, L2, L3 of Barium) respectively. The graph shows the tendency increase of mass attenuation coefficient values. When added barium oxide in the concentration 5-75 mol%. The trend of mass attenuation coefficient increasing because of the effect of high atomic number of barium oxide. However, the values of mass attenuation coefficient were found to be decrease when the gamma energy increasing, reflecting that the mass attenuation coefficient variation following the photon energy.

![Fig 1. The graph of total mass attenuation coefficient](image-url)
3.2. The total atomic cross-section and the total electronic cross-section

The total atomic cross-section refers to the number of electrons per atom but the total electronic cross-section is the number of electrons per area, calculation respectively by Equation 3 and 4. The result show in the fig1. and fig 2, when doped barium oxide, the values of the total atomic cross-section and the total electronic cross-section found that discontinuity by Compton edge in the energy rang of $1 \times 10^{-3}$ MeV, $1 \times 10^{-2}$ MeV and $1 \times 10^{-1}$ MeV same that the mass attenuation coefficient. The result by graph showed the tendency increase of the total atomic cross-section and the total electronic cross-section value. When doped barium oxide in the concentration 5-75 mol% respectively, the values of the total atomic cross-section and the total electronic cross-section were found to be decrease when the gamma energy increasing, reflecting that the mass attenuation coefficient variation following the photon energy, the result of the total atomic cross-section and the total electronic cross-section value same the mass attenuation coefficient value.

![Fig 2. The graph of total atomic cross-section](image1)

![Fig 3. The graph of total electronic cross-section](image2)
3.3. The effective atomic number and The electron density

For the effective atomic number and the electron density value calculated by equation 2 and 5. The both value found that discontinuity at lower energy at the energy rang $1 \times 10^{-3}$ MeV, $1 \times 10^{-2}$ MeV and $1 \times 10^{-1}$ MeV. The result tendency increase graph, when add barium oxide in the concentration 5-75 mol% respectively. The values of the effective atomic number and the electron density were found to be decrease when the gamma energy increasing. The result by graph of the effective atomic number and the electron density same trend graph of the total atomic cross-section, the total electronic cross-section, the total atomic cross-section and the total electronic cross-section. Also, the difference between the effective atomic number and the electron density in that electrons per atom and electrons per area respectively.

![Fig. 4. The graph of effective atomic number](image1)

![Fig. 5. The graph of electron density](image2)
4. Conclusion

The result of the mass attenuation coefficient, the total atomic cross-section, the total electronic cross-section, the effective atomic number and the electron density were completed for analysis. At lower energy, it was found that discontinuity from Compton edge at the energy range 1x10^3 MeV (M1, M2, M3 of Barium), 1x10^2 (K of phosphorus) MeV (K of phosphorus) and 1x10^3 MeV (L1, L2, L3 of Barium) respectively by. At the medium energy, the slope of the graph has an exponential decline decreases due to pair production. At higher energy, the slope of the graph tends to be constant. The graph of the effective atomic number and the electron density found that barium phosphate glasses was used as a good radiation shielding. From all the equations that were calculated it was found that, barium phosphate glass tends to protect against radiation when doped BaO where x = 5-75 mol% respectively.

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