PS13: อันตรกิริยาของแก้วตะกั่วบอเรต ที่พลังงานรังสีแกมมา 662 กิโลอิเล็กตรอนโวลต์

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บทคัดย่อ

งานวิจัยนี้ได้มีการศึกษาค่าสัมประสิทธิ์การลดทอนเชิงมวล ค่าภาคตัดขวางรวม และค่าเลขอะตอมยังผลของระบบแก้ว xPbO:(100-x)B_2O_3 เมื่อ $30 \leq x \leq 70$ (% โดยน้ำหนัก) ที่พลังงาน 662 กิโลอิเล็กตรอนโวลต์บนพื้นฐานของกฎการผสม ผลที่ได้พบว่า ค่าสัมประสิทธิ์การลดทอนเชิงมวลเพิ่มขึ้นเมื่อเพิ่มปริมาณตะกั่วอันเนื่องมาจากโอกาสในการเกิดการดูดกลืนโฟโตอิเล็กตริกที่สูงขึ้น อย่างไรก็ตามการกระเจิงคอมป์ตันเป็นอันตรกิริยาหลักของค่าสัมประสิทธิ์การลดทอนเชิงมวลรวมในแก้วตัวอย่าง โดยผลการทดลองสอดคล้องกับค่าทางทฤษฎีที่คำนวณจากโปรแกรม WinXCom สำหรับสมบัติการป้องกันรังสีของแก้วตัวอย่างมีค่าดีกว่าคอนกรีตกำบังรังสีแบบเดิมและดีกว่ากระจกหน้าต่างตามท้องตลาด ผลการทดลองนี้ชี้ให้เห็นถึงประโยชน์ของแก้วในการใช้เป็นวัสดุกำบังรังสี

คำสำคัญ: สัมประสิทธิ์การลดทอนเชิงมวล, เลขอะตอมยังผล, วัสดุกำบังรังสี, แก้ว

Interaction of Lead Borate Glass at 662 keV Gamma Rays

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Abstract

The mass attenuation coefficient, total interaction cross-section and effective atomic number of xPbO:(100-x)B_2O_3 where $30 \leq x \leq 70$ (% weight) glass system have been investigated at 662 keV on the basis of the mixture rule. The results are in good agreement with the theoretical values, calculated by WinXCom. Mass attenuation coefficients increase with PbO content, due to higher probability of photoelectric absorption in glass. However, Compton scattering gives dominant contribution to the total mass attenuation coefficients for the glass samples studied. The shielding properties of the glass samples are also better than ordinary shielding concretes and commercial window glass which can be used with advantage as transparent in visible region. These results indicate the potential of glasses as radiation shielding materials.

Keywords: Mass attenuation coefficients, Effective atomic numbers, Radiation shielding Materials, Glasses

1. Introduction

With increasing use of gamma-ray active isotopes in industry, medicine and agriculture, it has now become necessary to study shielding properties in various materials of technological and biological importance. 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[1]. For nuclear radiation shielding, a larger quantity of shielding material is required, therefore, study of propagation flux of radiation flux in shielding materials is essential requirement for shield design.

Major mass of nuclear radiation shield consist of layers of different concretes with different compositions and densities, but considerable variations in water content in concretes add uncertainly in calculation of attenuation coefficient and related shielding parameters[2]. Moreover they are also opaque to visible light. Materials to be used for shield design should have homogeneity of density and composition. Glasses are promising materials in this regard. Several glasses have been developed for nuclear engineering applications because they accomplish the double task of allowing visibility while absorbing radiations like gamma-rays and neutron, thus protection observer[2.3] . A good shielding glass should have high value of interaction cross-section and at the same time, mechanical and optical properties must be studied.

Study of the fundamentals of radiation interactions with materials has become an important research data for investigation. 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[4-9], elements[10-13], alloys[14-17] and compound[18-28] . Most of the previous measurements of attenuation coefficients and related shielding parameters have been performed on the materials in their solid and crystalline form[29-33], using various techniques.

In this work, we have measured gamma-rays interaction of lead borate glass at 662 keV (the mass attenuation coefficients, the atomic cross-sections and effective atomic number) of lead borate glasses system and then compare these parameters with theory using WinXCom program.

2. Theory

In this section we summarize theoretical relations used in the present work. A parallel beam of monoenergetic gamma-ray photons is attenuated in matter according to the Lambert-Beer law[34] :

$$\mathrm{I} = \mathrm{I}_0 \exp(-\mu_m \rho x) \tag{1}$$

where I_0 and I are incident and transmitted intensities of gamma radiation respectively, μ_m is the mass attenuation coefficient for alloy, x is the thickness of absorber (cm), ρ is the density of target (g/cm^3). Theoretical values of the mass attenuation coefficients of mixture or compound have been calculated by WinXCom, based on the mixture rule[34] . Thus:

$$\mu_m = \sum_i^n w_i (\mu_m)_i \tag{2}$$

where $(\mu_m)_i$ is the mass attenuation coefficient for the individual element in alloy, and w_i is the fractional weight of the element in the alloy. This mixture is valid when the effects of molecular binding, chemical and crystalline environment are negligible. The values of mass attenuation coefficients can be used to determine the total atomic cross-section ($\sigma_{t,a}$) by the following relation[1] :

$$\sigma_{t,a} = \frac{(\mu_m)_{alloy}}{N_A \sum_i^n (w_i / A_i)} \tag{3}$$

where N_A is Avogadro's number, A_i is atomic weight of the constituent element of alloy . Also the total electronic cross-section ($\sigma_{t,el}$) for the element is expressed by the following formula[1] :

$$\sigma_{t,el} = \frac{1}{N_A} \sum_{i}^{n} \frac{f_i A_i}{Z_i} (\mu_m)_i \tag{4}$$

where f_i is the number of atoms of the element i relative to the total number of atoms of all elements in alloy, Z_i is the atomic number of the i^{th} element in alloy. By using the mass attenuation coefficient of alloy, the effective atomic numbers were determined from eq. (5) [25].

$$Z_{eff} = \frac{\sigma_{t,a}}{\sigma_{t,el}} \tag{5}$$

3. Experiment

3.1 Sample preparation

The glass samples were prepared in by using high purity PbO and H_3BO_3 in the composition range of (weight %) xPbO:(100-x)B_2O_3 where $30 \leq x \leq 70$. Each batch weighs about 30 g was melt in porcelain crucibles by placing them in an electrical furnace for an hour, at 1,100 $^{\circ}$C till a bubble free liquid was formed, and quench in air. The quenched glasses were annealed at 500°C for 3 hour for reduce thermal stress, and cool down to the room temperature. All glass samples were measure thickness by micrometer. At the room temperature, densities (ρ) of all glass samples were measured by Archimedes's method using xylene as an immersion liquid. The density is calculated according to the formula;

$$\rho = \frac{w_A}{w_A - w_B} \times 0.8630 \quad \text{g/cm}^3 \tag{6}$$

where w_A the weight of the sample in air, w_B is the weight of the sample in xylene, and density of xylene is 0.8630 g/cm^3.

3.2 Transmission experiment and data processing method

The block diagram of good geometry set up is shown in Fig. 1. The source and absorber system were mounted on composite of adjustable stands. With the help of a screw arrangement the platform having material was also made capable of movement in the transverse direction to the incident beam for proper alignment (In this experiment fix at 13 cm). The sample detector solid angle was $< 0.5\times10^{-4}$ sr. The Cs^{137} radioactive source of 15mCi strength were obtain from office of atomic for peace (OAP), Thailand. The incident and transmitted gamma-rays intensities were determined for a fixed preset time in each experiment by recording the corresponding counts, using the $2'' \times 2''$ NaI(Tl) detector (BICRON model 2M2/2) having an energy resolution of 10.2% at 662 keV, with CANNERRA PMT base model 802-5. The statistical uncertainly was kept below 0.3 % by choosing the maximum counting time (fixed present time at 3,000 second) so that 10^5-10^6 counts were recorded in the full energy peak[2]. The dead time in this experiment was 0.73%-1.37%. The pulse shaping time is 0.5 μs. The optimum sample thickness was selected in this experiment, suggest from published literature[35-36].

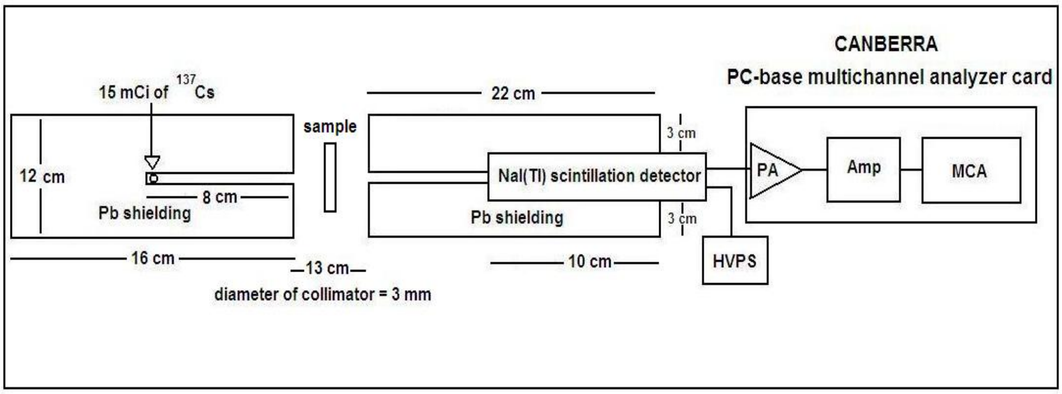

Figure 1 Experimental setup of transmission method

4. Results and Discussions

It is seen that the chemical composition, density and thickness of glass samples are given in Table 1. It is seen that the density of glass samples increase with higher PbO content, due to higher molecular weight of PbO compared to that of B_2O_3, therefore it is expected result.

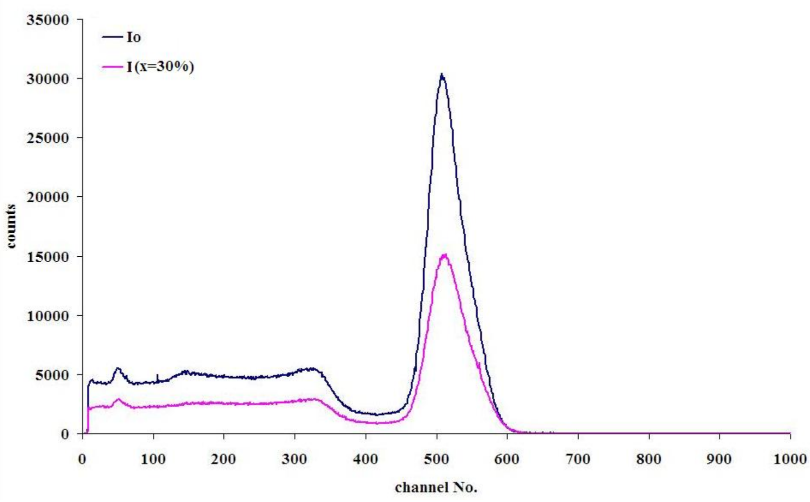

Figure 2. Typical Cs^{137} absorption spectra of glass samples for x = 30 %

Table 1.Chemical composition, density and thickness of glass samples.

Sample No.	xPbO	(100-x)B_2O_3	Density(g/cm^3)	Thickness (cm)
1	30	70	3.6003$\pm$0.0018	1.6632$\pm$0.0008
2	40	60	3.9700$\pm$0.0034	1.5421$\pm$0.0009
3	50	50	4.2898$\pm$0.0079	1.4712$\pm$0.0007
4	60	40	4.4794$\pm$0.0084	1.4013$\pm$0.0009
5	70	30	4.7651$\pm$0.0073	1.3822$\pm$0.0005

From transmission experiment are explained in theoretical section, we get I and I_0 for calculate mass attenuation coefficient, atomic cross section and effective atomic number using Eq. (1) – Eq. (5) respectively. Typical gamma-ray absorption spectra at 662 keV of glass system xPbO:(100-x) B_2O_3 (for x=30) are shown in Figure 2.

Table 2 lists the experimental and theoretical values of total mass attenuation coefficients and total atomic cross-sections of xPbO:(100-x)B_2O_3 glass system, where $30\leq x\leq 70$. In general, the experimental values agree with the theoretical values which are calculated from WinXCom. The mass attenuation coefficients and total atomic cross section increase with PbO content shows that the photon interaction probability is increase with higher PbO content. These results are shows the mixture rule for valuation of photon attenuation coefficients in these glasses are valid. The mass attenuation coefficient with sub-interaction of xPbO:(100-x)B_2O_3 glass system in this work (calculated by WinXCom) are show in Figure 3. The total mass attenuation coefficients were increased due to increasing of photoelectric absorption in glass samples. However, Compton scattering gives dominant contribution to the total mass attenuation coefficients for studied glass samples. These results are similarly behaviour with previous our work for Bi_2O_3-BaO-B_2O_3 glass system[38].

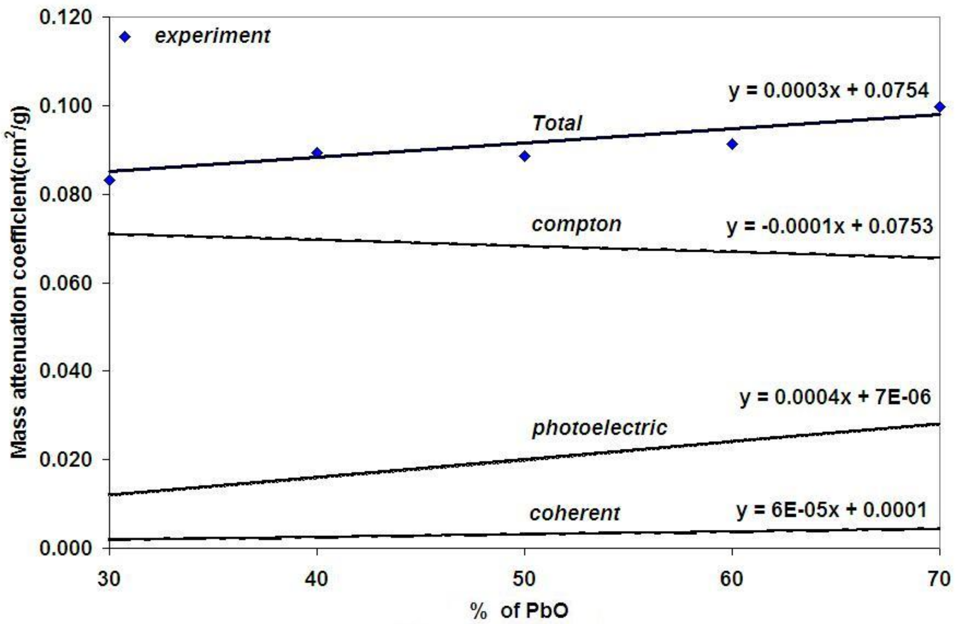

Figure 3. The mass attenuation coefficient with sub-interaction of xPbO:(100-x)B_2O_3 glass system.

Table 2. Total mass attenuation coefficient (cm^2/g), total atomic cross-section (b/atom) and effective atomic numbers (electron/atom) of glass samples.

% mol of PbO	$(\mu_m)_{th}$ ($\times10^{-2}$ cm^2/g)	$(\mu_m)_{ex}$ ($\times10^{-2}$ cm^2/g)	$(\sigma_{t,a})_{th}$ (b/atom)	$(\sigma_{t,a})_{ex}$ (b/atom)	$(Zeff)_{th}$ (electron/atom)	$(Zeff)_{ex}$ (electron/atom)
10	8.51	8.31±0.18	2.67	2.61	10.21	9.97
20	8.84	8.93±0.17	3.14	3.18	11.89	12.01
30	9.16	8.87±0.10	3.77	3.65	14.06	13.61
40	9.48	9.12±0.16	4.62	4.44	16.93	16.29
50	9.81	9.96±0.14	5.86	5.95	22.29	22.63

By using the experimental data of total mass attenuation coefficients, the effective atomic number for xPbO:(100-x)B_2O_3 glass system, evaluated from Eq. (5), are given in Table 2 along with theoretical value for each PbO concentration. It is seen that the experimental values of the effective atomic number are in good agreement with the theoretical ones. It has been found that the effective atomic numbers were increased with increasing PbO content, these results show the shielding parameter were better when increasing of PbO concentration.

5. Summary

In this work, the glass samples were prepared by using high purity PbO and H_3BO_3 in the composition range of xPbO:(100-x)B_2O_3 where $30 \leq x \leq 70$. The experimental values agree with the theoretical values, which are calculated from WinXCom. All parameters are increased with increasing of PbO concentration, shows that the photon interaction probability is increase with higher PbO content. From WinXCom calculation, total mass attenuation coefficients are increased due to increasing of photoelectric absorption in glass sample. However, Compton scattering gives dominant contribution to the total mass attenuation coefficients for studied glass samples. These results are varying useful for design radiation shielding glass and reflecting influence of Pb content in radiation shielding glass.

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