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Measurement of Total and Partial Mass Attenuation Coefficients of Oxide Glasses: A Radiation field

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Abstract : *The variation in mass attenuation coefficient μ for total and partial photon interaction processes for three different oxide glasses (65CaO-35Al_2O_3(OG1) , 20Na_2O-80SiO_2(OG2), and 20Na_2O-5Al_2O_3-75SiO_2 (OG3)), in the incident energy range from 10 keV to 100 GeV has been studied using software package XCOM and the effect of chemical composition on the values of μ is also interpreted graphically. Mass attenuation coefficient (μ) for the total photon interaction processes is initially high and decreases sharply with increase in incident photon energy up to 100 keV. Above 100 keV the rate of decrease of $\mu_{(total)}$ with incident photon energy is less and above 4 MeV $\mu_{(total)}$ increases slightly with further increase in incident photon energy. Significant variations due to chemical composition can be observed below 3 KeV and above 30 MeV incident energy.*

Keywords: *Gamma rays, mass attenuation coefficient and oxide glasses.*

I. INTRODUCTION

The mass attenuation coefficient (μ) measures the probability of interaction (scattering / absorption) of photon with the interacting medium. It is helpful in deriving many types of other photon interaction parameters such as molecular cross-section, atomic cross-section, equivalent and effective atomic numbers, electron density, buildup factor. The mass attenuation coefficient values of partial photon interaction processes such as photoelectric effect, Compton scattering, pair production and total are available in the form of software package XCOM from Berger and Hubbell [2, 3] by substituting the chemical composition/weight fraction of compound/mixture, the mass attenuation coefficient of the shielding materials will be generated in the energy range 1 keV - 100 GeV [4]. Hubble are published tables of mass attenuation coefficients and the mass energy absorption coefficients for 40 elements and 45 mixtures and compounds for 1 keV to 20 MeV in 1982.Hubbell and Seltzer replaced these tables in form of tabulation for all elements having $1 \leq Z \leq 92$ and for 48 additional substances for dosimetric interest [5].

Glasses are transparent to the visible light and the fact that their physical and chemical properties can be modified by changing their chemical composition and taking various types of preparation techniques, these materials are one of the effective alternatives to concrete and used as gamma ray shielding materials [6], [7], [8]. Glasses containing heavy metal oxide such as PbO have many advantages due to their high density and high refractive index. These properties are making them important materials for development of advanced optical telecommunication and gamma-ray shielding materials [9], [10],[11].

In our previous work [12], the energy absorption buildup factors have been studied as functions of penetration depth, incident photon energy and effective atomic number (Z_{eff}) of chosen oxide glasses. Our present investigation of mass attenuation coefficients (μ) of different oxide glasses for both total and partial photon interaction processes (Photo-electric absorption, coherent scattering, incoherent scattering and pair production) should be useful to scientists and workers in related fields, filling a gap in the available information. In recent studies, attenuation coefficient for different energies for various samples in solid/ liquid/mixtures and alloys is reported by many workers [13-33].

In this paper, detailed calculations have been made to study the effect of chemical composition on μ for total and partial interaction processes in three different oxide glasses covering the energy range from 10 keV to 100 GeV.

II. THEORY

A narrow beam of mono-energetic photons having an initial intensity I_0 is attenuated to intensity 'I' after passing through a layer of material with mass-per-unit-area 'x', according to the exponential law:

$$I = I_0 e^{-\mu/\rho . x} \qquad \text{----- (1)}$$

Where μ/ρ is the mass attenuation coefficient, Eq. (1) can be rewritten as:

$$\frac{\mu}{\rho} = \frac{\ln\left(I_0 / I\right)}{x} \qquad \text{----- (2)}$$

Therefore, mass attenuation coefficient ($\mu_m = \mu/\rho$) can be calculated by substituting the measured values of I_0 , I and x in Eq. (2). The mass attenuation coefficient ($\mu_m = \mu/\rho$) is of more fundamental importance than linear attenuation coefficient (μ) because all mass attenuation coefficients are independent of the density and physical state (gas, liquid or solid) of the absorber.

The attenuation coefficient is interaction process dependent i.e. the attenuation coefficient is a measure of the average number of interactions between incident photon and matter that occur in a given mass-per-unit area thickness of the material encountered. It is distinguished sharply from the absorption coefficient which is always a smaller quantity and absorption coefficient measures the energy absorbed by the medium. Depending on its energy, gamma rays interact with

matter through different processes such as photoelectric effect, Compton scattering, pair-production, thomson scattering, nuclear photodisintegration and nuclear resonance scattering. Photons interact with matter and lose their energy because of the three main processes which are, photoelectric effect, Compton scattering and pair-production.

III. RESULT AND DISCUSSION

The results of the present investigation are shown graphically in figs. 1-9, where μ is given as a function of incident photon energy in all photon interaction processes. The chemical composition in grams for 100 grams of different types of oxide glasses are shown in table. 1 [1].

In fig. 1-3, μ values of OG1, OG2, and OG3 for total and partial interactions have been plotted against the incident photon energy. The graphs of mass attenuation coefficient for all the photon interactions are approximately similar to those of elements of low atomic number such as Na, Al, Si and Ca etc. because of the fact that effective atomic number values of the chosen samples lie in this range.

In the present work, the effect of chemical composition of oxide glasses on μ and the variations of μ with incident photon energy for all interactions are discussed in the following paragraphs.

Mass attenuation coefficient (μ) for the total photon interaction processes is initially high and decreases sharply with increase in incident photon energy up to 100 keV. Above 100 keV the rate of decrease of $\mu_{(total)}$ with incident photon energy is less and above 4 MeV $\mu_{(total)}$ increases slightly with further increase in incident photon energy. This behavior is due to dominance of different interaction processes in different incident photon energies i.e. below 100 keV photo electric process is dominant, from 100 keV to 4 MeV Compton scattering and above 4 MeV pair-production process is dominant.

It is also clear in fig. 4 that the oxide glass OG1, contains a higher percentage of heavy element such as calcium, has slightly lower values of $\mu_{(total)}$ in lower energy region whereas it has slightly higher values in the high energy region (after 10 MeV to 10^5 MeV) as compared to other oxide glasses.

The above observations of fig. 4 can also be extended to the other figures (5-9) in which the effect of oxide glasses chemical composition on μ is investigated for partial photon interactions (photo-effect (photo), coherent and incoherent scattering, pair production in the electric field, and pair production in the nuclear field) for same choosing samples.

From fig. 5, it is observed that the value of $\mu_{(photo)}$ decreases rapidly with increase in incident photon energy for all the selected materials. It may due to reason that photo-electric cross-section varies inversely with incident photon energy as $E^{7/2}$. In the lower energy region values of $\mu_{(photo)}$ of OG1 slightly lower than other oxide glasses, but in the energy region of 0.3-100 MeV the values of OG1 are higher ,which is due to chemical composition of oxide glasses as $\mu_{(photo)}$ is further strongly dependent on atomic number of interacting materials as z^{4-5}. It implies that its shielding behavior is better in this energy region.

In figs. (6,7) it is observed that the values of $\mu_{(coh.)}$ decrease sharply with increase in incident photon energy for all chosen samples after the 10 keV and values of $\mu_{(incoh.)}$ rate of decrease is comparatively lower. This decrease in values with increase in incident photon energy may be due to the reason that $\mu_{(coh.)}$ and $\mu_{(incoh.)}$ is inversely proportional to incident photon energy E. The variations in the values of $\mu_{(incoh.)}$ due to chemical composition is low but it is almost same in case of coherent scattering.

From the above results it is interpreted that decreasing rate of values of $\mu_{(photo)}$ with incident photon energy is higher than $\mu_{(coh.)}$ decreasing rate. And the variation in $\mu_{(photo)}$ due to chemical composition can be seen clearly which is not significant in case of $\mu_{(coh.)}$. Above results clearly explain the variation of $\mu_{(total)}$ below 4 MeV in fig. 4.

The variation of μ for pair production in electric field and nuclear fields are shown in figs 8-9 respectively. In both cases, the values of $\mu_{(pp)}$ increases slightly with increase in incident photon energy up to 400 MeV but beyond this incident energy the values of $\mu_{(cpp)}$ remains almost constant. It may be due $\mu_{(pp)}$ is directly proportional to logE. For pair production in the nuclear field, the values of $\mu_{(pp)}$ of chosen samples show significant variation (fig. 9) but slight variation is observed for $\mu_{(pp)}$ in the electric field (fig. 8). It may be due to pair production in nuclear field is Z^2 dependent, whereas the Z dependence of pair production in the electric field is almost linear. In the high incident photon energy range, the variation is observed in $\mu_{(total)}$ (fig. 4) is because of Z^2 – dependence of the pair production in the nuclear field.

IV. FIGURES AND TABLES

Table 1: Chemical composition of oxide glasses (for 100 gm. of glass) [1].

Chosen Samples	CaO (gm.)	Al_2O_3(gm.)	Na_2O(gm.)	SiO_2(gm.)
65CaO-35Al_2O_3 (OG1)	50.5	49.5	----------	---------
20Na_2O-80SiO_2 (OG2)	----------	----------	20.5	79.5
20Na_2O-5Al_2O_3-75SiO_2 (OG3)	----------	8.15	19.8	72.0

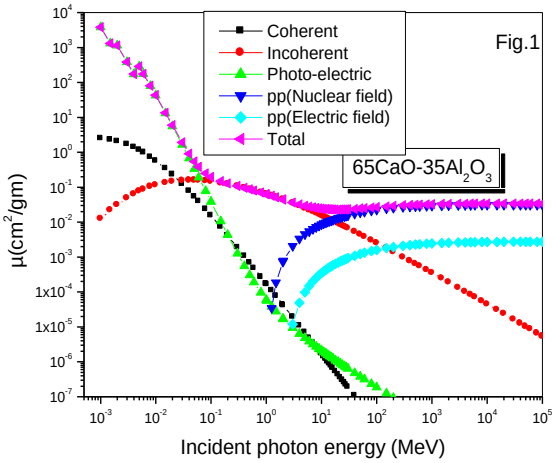

Fig.1: Variation of Mass attenuation coefficients of oxide glass (65 CaO-35 Al_2O_3) with incident photon energy (MeV) for different photon interaction processes.

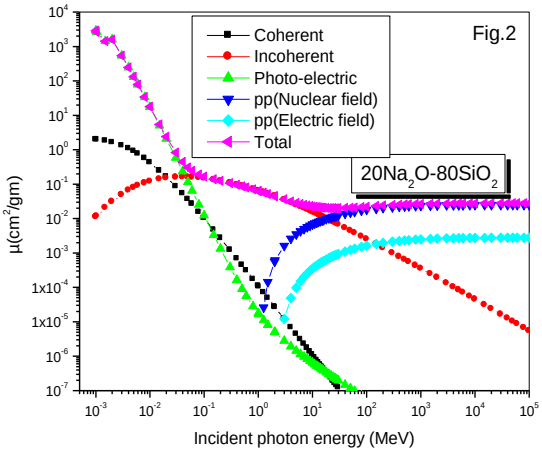

Fig.2: Variation of Mass attenuation coefficients of oxide glass (20 Na_2O-80SiO_2) with incident photon energy (MeV) for different photon interaction processes.

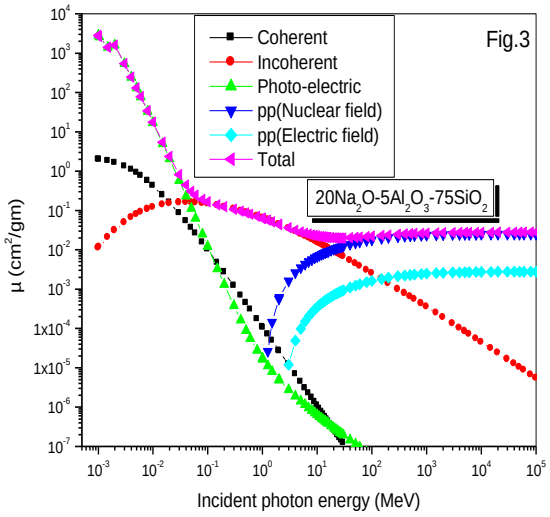

Fig.3: Variation of Mass attenuation coefficients of oxide glass (20 Na_2O-5Al_2O_3-75SiO_2) with incident photon energy (MeV) for different photon interaction processes.

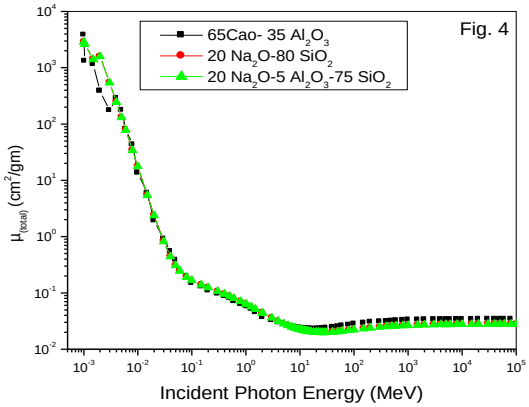

Fig.4: Variation of Total mass attenuation coefficients of all oxide glasses with incident photon energy (MeV).

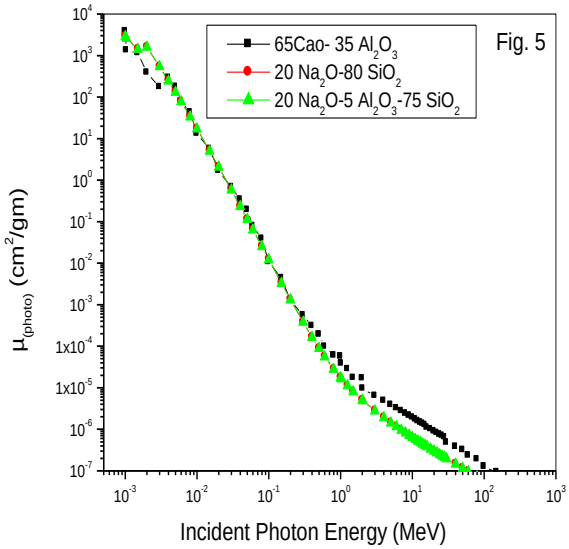

Fig.5: Variation of mass attenuation coefficients of all oxide glasses with incident photon energy (MeV) for photo electric absorption.

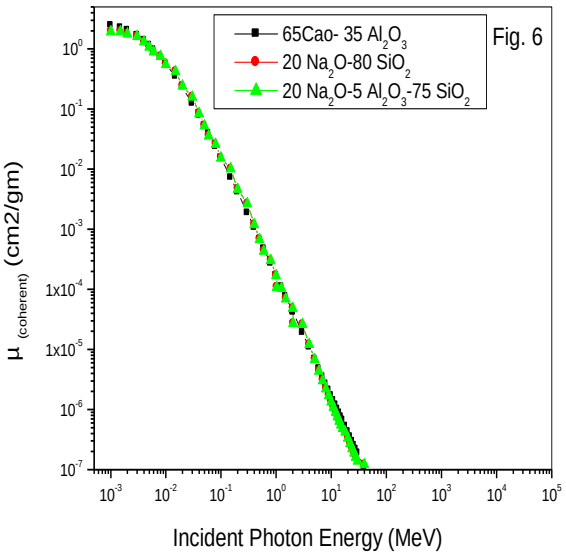

Fig.6: Variation of mass attenuation coefficients of all oxide glasses with incident photon energy (MeV) for coherent scattering.

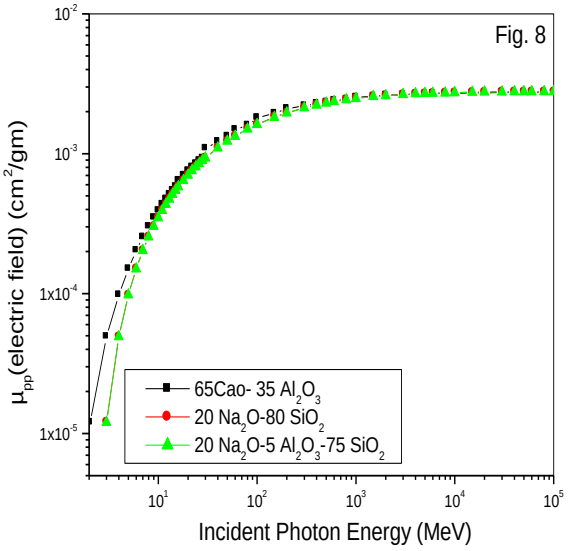

Fig.8: Variation of mass attenuation coefficients of all oxide glasses with incident photon energy (MeV) for pair production in the electric field.

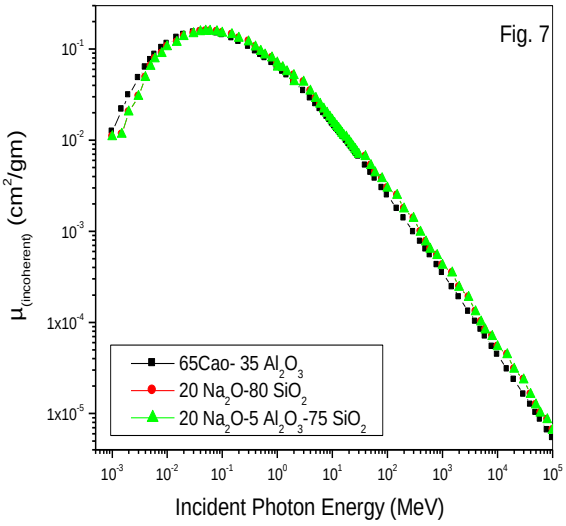

Fig.7: Variation of mass attenuation coefficients of all oxide glasses with incident photon energy (MeV) for incoherent scattering.

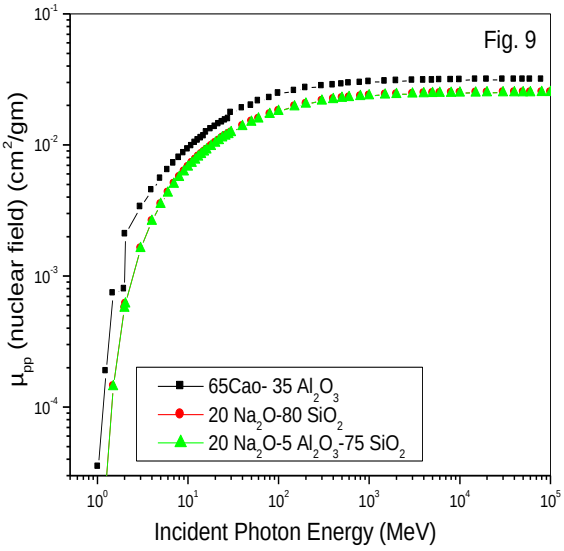

Fig.9: Variation of mass attenuation coefficients of all oxide glasses with incident photon energy (MeV) for pair production in the nuclear field.

V. CONCLUSION

- The mass attenuation coefficient (μ) is also deriving various other photon interaction parameters such equivalent and effective atomic numbers, electron density, buildup factor etc..
- Mass attenuation coefficient (μ) of chosen samples for the total photon interaction processes is high and decreases rapidly with increase in gamma photon energy up to 100 keV. After 100 keV the variation of μ with incident photon energy is less and above 4 MeV μ increases slightly with increase in photon energy. This behavior is due to dominance of different interaction processes in different incident photon energies i.e. below 100 keV photo electric process is dominant up to 100 keV after that Compton scattering up to 4 MeV and pair-production process is dominant above 4MeV. Mass attenuation coefficient helpful for detail study in shielding effectiveness of different types materials /mediums.
- In the three photon interaction processes, the value of μ also vary due to chemical composition. In the lower energy region values of $\mu_{(photo)}$ of OG1 slightly lower than other oxide glasses, but in the energy region of 0.3-100 MeV the values of OG1 are higher. The variations in the values of $\mu_{(incoh.)}$ due to chemical composition is low but it is almost same in case of coherent scattering. For pair production in the nuclear field, the values of $\mu_{(pp)}$ of chosen samples show significant variation but slight variation is observed for $\mu_{(pp)}$ in the electric field.

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