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# Z-Dependence of Photon Interactions in $La_3Nb_{0.5}Ga_{5.5}O_{14}$ and $La_3Ga_5SiO_{14}$ Crystals

**K. Nanda Gopal**
Scientific Assistant, India Meteorologial Department, Kakinada, AP., India
**K. Jyothi**
Lecturer & Head, Department of Physics, Govt. College (A) Rajahmundry, A.P, India
**A. S. Nageswara Rao**
Professor & Head, Department of Physics, Kakatiya University, Warangal, A.P., India

***Abstract:***
*To study the photon absorption in crystals the effective atomic number is an important parameter. Using the chemical composition, the effective atomic numbers are calculated like other properties of the crystal the photon absorption coefficients of these crystals are compared at different energies. These Mass absorption coefficients are calculated and compared with the theoretically available data of X-Com.*

***Keywords:*** *Chemical composition, Effective atomic number, Mass attenuation coefficient, X-com.*

## 1. Introduction

Langasite-type single crystals have been intensively studied as piezoelectric materials due to their high piezoelectric constants and electromechanical coupling factor at high temperature. These materials are expected to be applied in various sensor devices used at high temperature such as the combustion pressure sensor [1,2]. Growth and physical properties of disordered langasite-type crystals of La3Ga5SiO14 (LGS), La3Nb0.5Ga5.5O14 (LNG), and La3Ta0.5Ga5.5O14 (LTG) have been studied for a long time [3-5].

The attenuation coefficient measurements have received a great stimulus in recent years because of their usefulness in calculating radiation attenuation, transport and energy deposition in medical physics, reactor shielding, and industrial radiography and in a variety of other areas in addition to X-ray crystallography. This energy absorption in a given medium can be calculated by well-established formulae if certain constants like effective atomic number and electron density of a medium are known.

The physical basis of this method is a representation of the X-ray or gamma ray attenuation coefficients as a sum of terms depending on atomic number, photon energy and electron density. It is observed that a single atomic number cannot be used to characterize the photon interactions over extended energy ranges for a compound or a composite material. In place of effective atomic number, a quantity called the effective atomic number is defined for these materials. It is also noted that Z-exponents depend on both photon energy and the composition of the absorber.

In this paper, the effective atomic number of $La_3Nb_{0.5}Ga_{5.5}O_{14}$ and $La_3Ga_5SiO_{14}$ crystals [6] has been calculated for different energies by studying the photon interactions with these crystals at theses energies. The Z exponents and attenuation coefficients are also calculated.

## 2. The Method of Computation

Conventionally the elemental cross section per electron is said to be directly proportional to $Z^m$ where m depends on the type of process considered. A compound or a mixture may be considered as a single element with an effective atomic number $\overline{Z}$ given by,

$$\overline{Z} = \left[ \sum_i \alpha_i Z_i^{m-1} \right]^{\frac{1}{m-1}} \qquad \text{..... (1)}$$

where $Z_i$ is the atomic number and $\alpha_i$ is the fractional content of $i_{th}$ element in the compound or mixture.

It follows that the mass attenuation coefficient [7-10] can be expressed as

$$\frac{\mu}{\rho}(E) = n_0 \left[ K_{photo}(E)\overline{Z}^{m-1} + K_{coh}(E)\overline{Z}^{=n-1} + {}_e\sigma_{KN} \right]$$

..... (2)

where $n_0$ is the electron density and K is a constant at a given energy. The variation of elemental photon cross section per atom ($_a\sigma$) with atomic number was studied using the relationship

$$_a\sigma = K(E)Z^m \text{ ..... (3)}$$

The partial mass attenuation coefficient for a compound
[11-12] was assumed to be.

$$\frac{\mu_\tau}{\rho} = K_{photo}(E)(\overline{Y})^p \quad \text{..... (4)}$$

with

$$\overline{Y} = n_0 \overline{Z}^{m-1}$$

A plot of $\ln\left(\frac{\mu_\tau}{\rho}\right)$ versus $\ln(\overline{Y})$ gives a straight line of slope p. This regression, using the calculated values of $\ln\left(\frac{\mu_\tau}{\rho}\right)$ and $(\overline{Y})$ for all the compounds was calculated for a number of values of m and the value corresponding to p=1 was interpolated. When p=1 the equation resolved into the relationship given in equation (2). Similar calculations were made for attenuation coefficient due to coherent scattering.

It has been pointed out [13-15] that equation (2) does not describe variation of the coherent, incoherent scattering and atomic photo effect to the required accuracy unless the exponents are allowed to be dependent on both E and Z. The total mass attenuation coefficient may be calculated from

$$\frac{\mu}{\rho}(E) = n_0\left[{}_e\sigma_{KN} + 103.3\left(\frac{\overline{Z}^{m-1}}{E^{3.65}}\right) + 6.9\left(\frac{\overline{=}^{n-1}}{E^{2.01}}\right)\right]x10^{-24} \text{.....(5)}$$

**3. Results and Discussion**

In this paper, the effective atomic number of $La_3Nb_{0.5}Ga_{5.5}O_{14}$ (LNG) and $La_3Ga_5SiO_{14}$ (LGS) crystals has been calculated for the energies 10,20,30 and 40keV.

The energies, the values of Z-exponents for atomic photo effect (m) and coherent scattering (n), Z effective for atomic photo effect and coherent scattering for LNG and LGS are shown in the table 1 and table 2 respectively. The value of Z-exponent for atomic photo effect (m) increases as photo energy increases and the effective atomic number for atomic photo effect and coherent scattering also increases as energy increases. The calculated and theoretical (X-COM) [16], of total mass attenuation coefficients are also tabulated in table 3. All these are found to be in good agreement. Fig 1 and Fig 2 show variation of effective atomic number for photo and coherent with energy for LNG and LGS respectively. The variation of total attenuation coefficient for LNG and LGS with energy is shown in Fig 3. This clearly indicates that the attenuation coefficient decreases as the energy increases and there is a steep fall of attenuation coefficient at low energies only.

| Name of the Compound | Energy keV | m | n | Zeff atomic photo | Zeff cohe-rent |
|---|---|---|---|---|---|
| $La_3Nb_{0.5}Ga_{5.5}O_{14}$ | 10 | 2.54 | 3.95 | 19.37 | 9.30 |
| | 20 | 2.76 | 4.36 | 21.70 | 11.09 |
| | 30 | 2.86 | 4.45 | 22.17 | 11.87 |
| | 40 | 2.98 | 4.72 | 23.52 | 12.80 |

*Table 1: Energy, m, n, Z effective photo, Z effective coherent of LNG*

| Name of the Compound | Energy keV | m | n | Zeff atomic photo | Zeff cohe-rent |
|---|---|---|---|---|---|
| $La_3Ga_5SiO_{14}$ | 10 | 2.52 | 3.96 | 19.02 | 8.76 |
| | 20 | 2.75 | 4.33 | 21.16 | 10.59 |
| | 30 | 2.82 | 4.42 | 21.65 | 11.14 |
| | 40 | 2.88 | 4.71 | 23.16 | 11.60 |

*Table 2: Energy, m, n, Z effective photo, Z effective coherent of LGS*

| Name of the Compound | Energy keV | Total mass attenuation coefficient ($cm^2/g$) | |
|---|---|---|---|
| | | calculated | Theoretical [12] |
| $La_3Nb_{0.5}Ga_{5.5}O_{14}$ | 10 | 39.32 | 39.21 |
| | 20 | 15.63 | 15.66 |
| | 30 | 5.25 | 5.25 |
| | 40 | 5.18 | 5.16 |
| $La_3Ga_5SiO_{14}$ | 10 | 38.44 | 38.19 |
| | 20 | 13.19 | 13.33 |
| | 30 | 4.44 | 4.45 |
| | 40 | 4.76 | 4.80 |

*Table 3: Total mass attenuation coefficients*

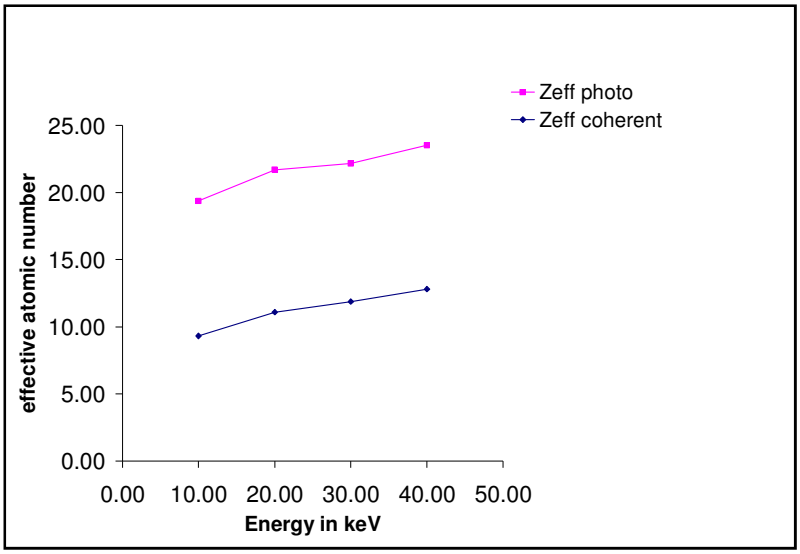


*Figure 1: Variation of effective atomic number of LNG crystal with energy*

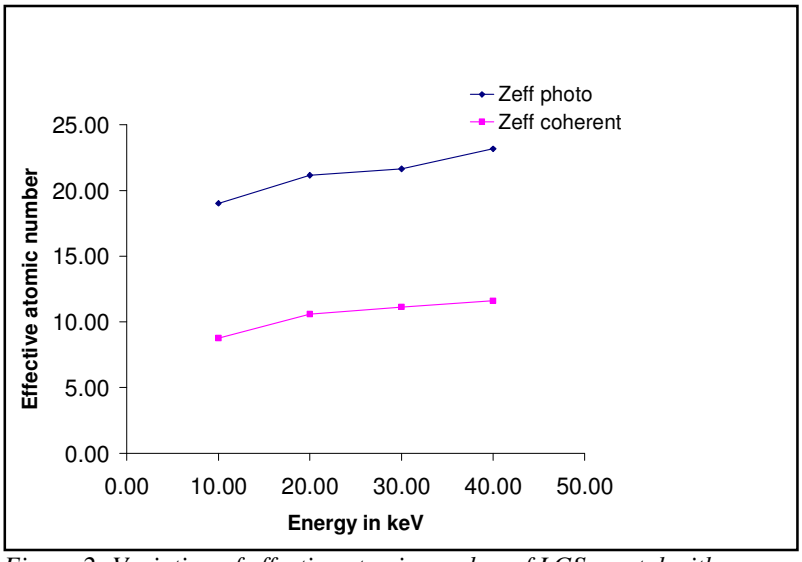


*Figure 2: Variation of effective atomic number of LGS crystal with energy*

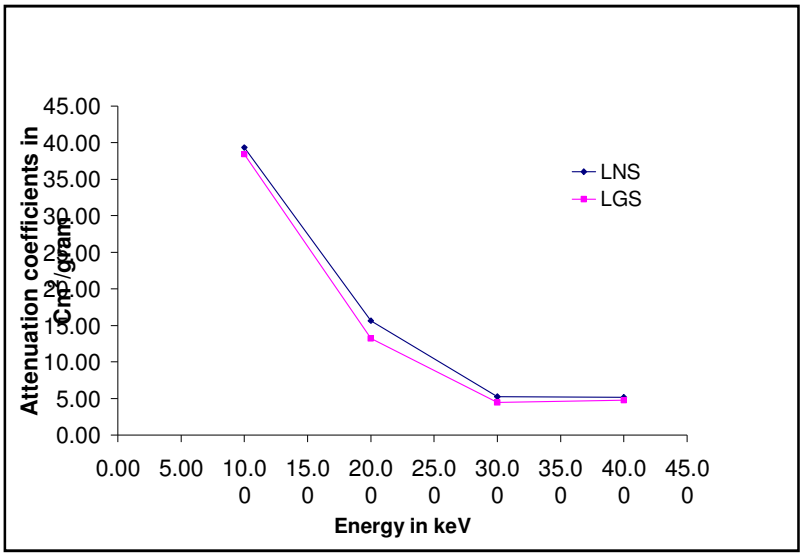


*Figure 3: Variation of attenuation coefficient with energy*

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