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MASS ATTENUATION COEFFICIENTS OF COMPOUNDS IMPORTANT FOR X-RAY IMAGING: EMPIRICAL MODELLING AND ESTIMATION OF ORDER OF DEPENDENCE ON PHOTON INTERACTION ENERGY

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ABSTRACT

Mass attenuation coefficients of some important X-ray imaging photoconductor materials namely Mercuric Iodide, Lead Oxide, Lead Iodide and Cadmium Zinc Tellurium are simulated for different photon interaction energies. The order of dependence of mass attenuation coefficient on photon interaction energy is determined and corresponding empirical models were developed for each compound. The order of dependence and hence the empirical formula is found to be different in two different energy ranges. In the energy range of 1KeV-110KeV, the order of dependence of mass attenuation coefficient on photon interaction energy is found to be approximately -1.6 and in the energy range of 110KeV-20MeV, the order of dependence is found to be approximately -2.45 for all the compounds.

Keywords: Empirical model, Mass attenuation co-efficient, Photon interaction energy, Photoconductor, X-ray imaging.

INTRODUCTION

The photon mass attenuation coefficient is one of the basic quantities required to determine the penetration of X-ray and γ-ray in matter. Particularly, in X-ray imaging, the knowledge of the mass attenuation coefficients of photoconductor materials is an essential requirement [1]. The mass attenuation coefficient provides a wide variety of information about fundamental properties of a matter in the atomic and molecular level.

The attenuation suffered by a narrow beam of monochromatic radiation perpendicularly incident upon a flat layer of material is governed by the exponential absorption law known as Lambert Beer's Law [2]:

$$I(x) = I_o exp\left[-\left(\frac{\mu}{\rho}\right)x\right] \quad (1)$$

where $\frac{\mu}{\rho}$ is the mass attenuation coefficient, I_o and $I(x)$ are the respectively intensities of incident and transmitted (attenuated) X-ray photons and x is the mass per unit area of the material given by,

$$x = \pm t \quad (2)$$

where σ is the macroscopic material density and t is the thickness of the material [3].

In photo-detection setup of X-ray, photoconductor layer is an important part. Polycrystalline Mercuric Iodide and Lead Iodide are commonly used photoconductor materials [4]. Additionally, Lead oxide and Cadmium zinc telluride are also used in photo-detection. In this study, mass attenuation coefficients of the four aforementioned compounds are simulated and analysed for a range of photon interaction energy. Furthermore, empirical models of mass attenuation co-efficient for different energy ranges have been developed. From the empirical models, the order of dependence of mass attenuation coefficients on photon interaction energy has been estimated.

MODEL AND SIMULATION

The mass attenuation coefficient for a mixture or compound (assumed to be or approximated as homogeneous) can be found approximately using [5]:

$$\frac{\mu}{\rho} = \sum_i w_i \left(\frac{\mu}{\rho}\right)_i \tag{3}$$

Where w_i is the fraction by mass of the species in the compound and $\left(\frac{\mu}{\rho}\right)_i$ is the mass attenuation coefficient of that species [5].

DATA ACQUISITION

The mass attenuation co-efficient data of elements used in this study were acquired from the website of National Institute of Standards and Technology [6-12].

RESULT AND DISCUSSION

Firstly, we have simulated mass attenuation coefficients for a range of photon interaction energy for the four compounds under investigation. Fig.1 through Fig. 4 show the mass attenuation coefficient vs photon interaction energy plots for Mercuric Iodide, Lead Oxide, Lead Iodide and Cadmium Zinc Telluride respectively in the energy range of *1KeV-20MeV*.

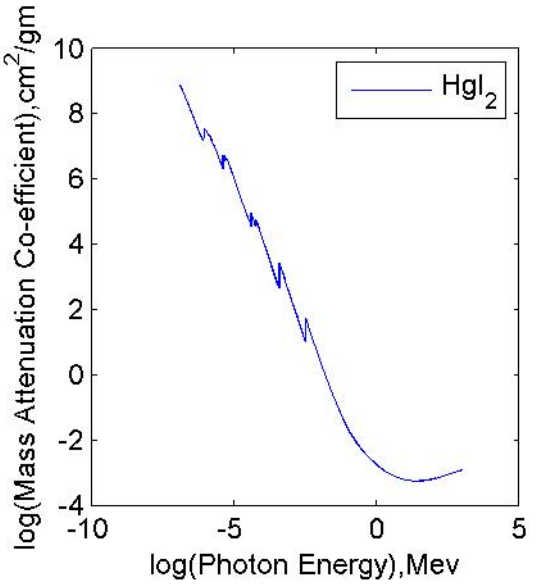

Fig 1. Mass Attenuation co-efficient vs Photon Energy for HgI_2 in the energy range 1KeV to 20 MeV.

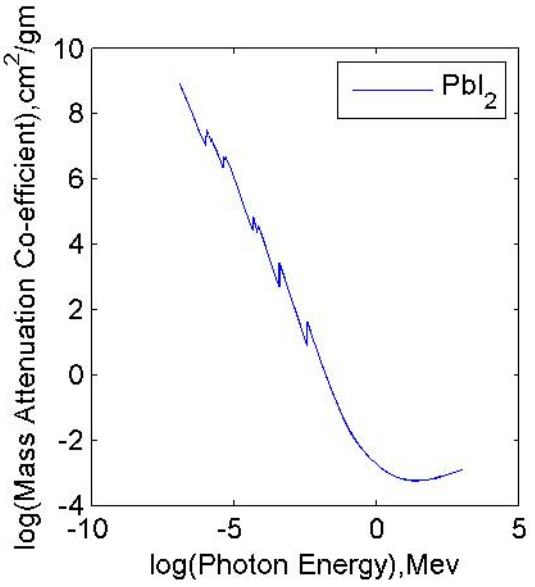

Fig 2. Mass Attenuation co-efficient vs Photon Energy for PbI_2 in the energy range 1KeV to 20 MeV.

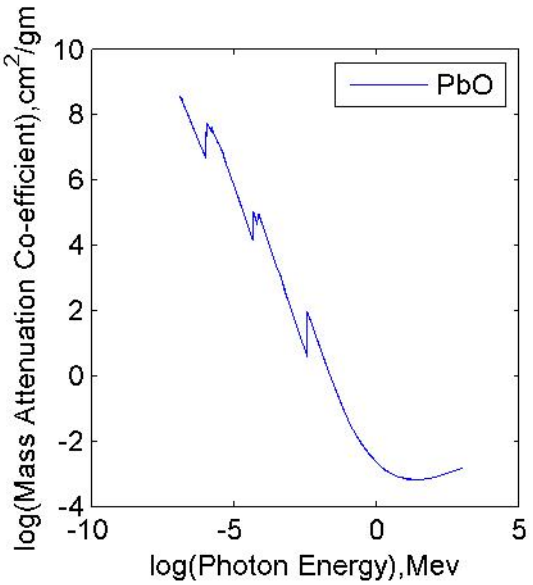

Fig 3. Mass Attenuation co-efficient vs Photon Energy for PbO in the energy range 1KeV to 20 MeV.

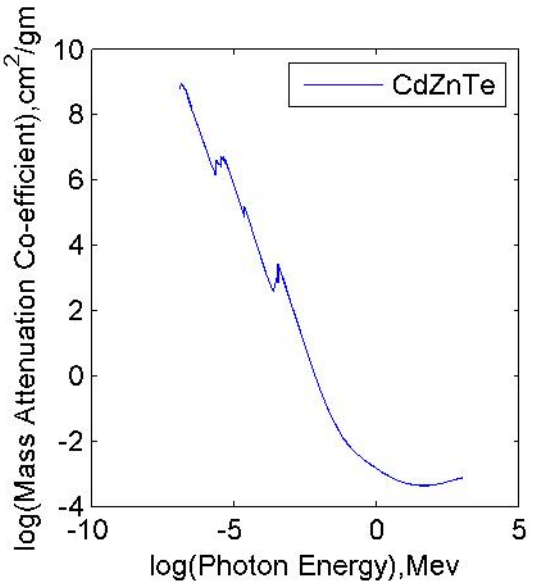

Fig 4. Mass Attenuation co-efficient vs Photon Energy for CdZnTe in the energy range 1KeV to 20 MeV.

The absorption edges are observed for each of the plots and listed in Table 1.

TABLE 1
The absorption edges observed for the compounds under investigation

Compound	**K edge**	**L edge**	**M edge**	**N edge**	**O edge**
HgI_2	0.082 MeV	0.03 MeV	0067 MeV	0.0024 MeV	0.0015 MeV
PbI_2	0.082 MeV	0.03 MeV	0.0067 MeV	0.0025 MeV	0.0015 MeV
PbO	0.082 MeV	0.011 MeV	0.004 MeV		
CdZnTe	0.048MeV	0.0183 MeV	0.004 MeV		

The mathematical relationship between the mass attenuation co-efficient and photon energy was investigated by analysing the acquired data. As evident from the plots, the variation of atomic mass coefficients of the compounds with respect to the photon interaction energy follows a common trend which is distinctive for two distinct photon energy ranges. We have chosen the first photon energy range to be *1KeV-110KeV* where all the plots follow a similar trend. The second photon energy range is *110KeV-20MeV*; where the plots follow another similar trend.

Hence we have developed an empirical model for each of the compounds consisting of two separate equations for two energy ranges. To determine the order of dependence of mass attenuation coefficient on photon interaction energy, we have chosen a suitable form of equation as shown in equation (4).

$$\frac{\text{«}}{\text{°}} = \sim \times E^{-} \quad + ¢ \tag{4}$$

Then we have employed MATLAB curve fitting tool *cftool* to obtain the values of the coefficients α, β and δ in the above equation for each of the compounds under investigation. The coefficients have been extracted from *cftool* with a confidence bound of 95%. Table 2 shows the values of these coefficients acquired by this process.

TABLE 2

Numerical values of the coefficients α, β and δ of the empirical equation (4)

Energy Ranges	***1KeV-110KeV***				***110KeV-20MeV***			
Compound	HgI_2	PbI_2	PbO	CdZnTe	HgI_2	PbI_2	PbO	CdZnTe
α	0.087	0.085	0.087	0.086	0.012	0.010	0.017	0.010
β	1.637	1.642	1.622	1.644	2.424	2.458	2.451	2.44
δ	0	0	0	0	0.046	0.049	0.049	0.049

The important parameter here is the order of dependence, β, of mass attenuation coefficient on photon interaction energy. We can see that in the energy range of *1KeV-110KeV*, the mass attenuation coefficient is proportional to approximately the -1.6^{th} order of photon interaction energy (E) and in the energy range of *110KeV- 20MeV*, the mass attenuation coefficient is proportional to approximately the -2.45^{th} order of photon interaction energy. To summarize,

$$\frac{\mu}{\rho} \sim E^{-1.6}, 1KeV \le E \le 110KeV \quad (5)$$

And

$$\frac{\mu}{\rho} \sim E^{-2.45}, 110KeV \le E \le 20MeV \quad (6)$$

CONCLUSION

In this study, we have explored in an extensive scope the dependence of mass attenuation coefficients of several compounds important as photoconductor materials used in X-ray imaging on their corresponding photon interaction energies. The theory provided us with a formula to determine the mass attenuation coefficients of the compounds using the weight fractions and mass attenuation coefficients of the respective elements. However, the existing theory does not give any indication about the trend or order of dependence of mass attenuation coefficient on photon interaction energy. We have developed empirical models to find such dependence. For each compound, we have given two separate formulas for two different photon interaction energy ranges. We have observed that for all the compounds, the dependence of mass attenuation coefficient on photon interaction energy in a particular energy range is fairly of the same order. The approach we have adopted in our study can aptly be employed to investigate the order of dependence of mass attenuation coefficients of other compounds. Since we have found that for four different compounds, the order of such dependence and the other parameters of the empirical models are almost the same, we can presume that our model will hold fairly well for other compounds as well in the energy ranges we have explored. Whether our empirical models hold for other photon interaction energy ranges calls for further investigation.

REFERENCES

[1] D. F. Jackson and D. J. Hawkes, 1981.X-ray attenuation coefficients of elements and mixtures. Physics Reports. 70(3),169–233.
[2] N.A.Alallak and S.S.Sarhan.2012.Factors Affecting Gamma Ray Transmission.Jordan Journal of Physics.5(2),77-88.
[3] http://physics.nist.gov/PhysRefData/XrayMassCoef/chap2.html

[4] Md.Ashikuzzaman,Jisan Ali,R.Adib,M.M.Hossain,and Shaikh Asif Mahmood,2016.HgI_2 As X-ray Imager: Modulation Transfer Function Approach .IJMRET.1(2). 1-4.
[5] L.Holmes, D.Treacher, C.Michelbach,2014.P1_6 Tipler Radiation Shielding. Journal of Physics Special Topics.13,1-2.
[6] http://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z80.html
[7] http://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z53.html
[8] http://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z82.html
[9] http://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z08.html
[10] http://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z48.html
[11] http://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z30.html
[12] http://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z52.html