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Issue Date	2015

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A Research Paper Submitted to Myanmar

Academy of Arts and Science

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June, 2015

Effective Atomic Numbers of $CaSO_4$ and $BaSO_4$ Dosimetric Compounds for Gamma Energy Absorption

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Abstract

Mass attenuation coefficient, effective atomic cross-section and effective atomic number of $CaSO_4$ and $BaSO_4$ compound samples were determined for the energy 81keV, 356keV, 511keV, 662keV, 1173keV, 1274keV and 1332keV by using gamma ray transmission method. The gamma rays emitted from ^{22}Na, ^{133}Ba, ^{137}Cs and ^{60}Co point sources have been used to be measured gamma rays transmission for the compounds. It is found that the mass attenuation coefficient and atomic cross-section decrease with increasing gamma ray energy. The variations of effective atomic number (Z_{eff}) with photon energy for the compounds were dictated by photon interaction process.

Key words: 10.gamma ray transmission, thermoluminescence compounds, atomic cross section and effective atomic number

Introduction

The gamma spectrometric parameters which include mass attenuation coefficient, effective atomic cross-section and the effective atomic number are basic quantities required in studying the interaction of gamma ray with matter. They are also used to determine the minor component in a major component material. The scattering and absorption of γ-radiations are related to atomic cross-section and effective atomic number of the material.

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These parameters have physical meaning and their numerical value allows many characteristics of a material to be visualized. Several commercially available thermoluminescent and photoluminescent materials are used as radiation detectors in biological and industrial dosimetry of ionizing radiations.

The measurement of attenuation coefficients of photons in biological and other materials is of significant interest in industrial, agricultural, biological and medical applications. From the recent studies, Kateb (2000) measured the mass attenuation coefficients at 511keV, 662keV and 1274 keV for lithium, sodium and potassium chloride salt solution and employed the results to determine gamma spectrometric parameters for the solutions. [1] Moreover, Gowda and Yashoda (2004) extended the study on photon mass attenuation coefficients, effective atomic cross section and effective atomic number for some thermoluminescent dosimetric compounds, such as LiF, $CaCO_3$, $CaSO_4$, $SrSO_4$, $CdSO_4$, $BaSO_4$ and $C_4H_6BaO_4$ at the energies 662keV, 1173keV and 1332keV.[2]

In this research work, we have presented the measured values of total attenuation coefficient, atomic cross-section and effective atomic number of $CaSO_4$ and $BaSO_4$ compounds at 81keV, 356kV, 511keV, 662keV, 1173keV, 1274keV and 1332keV obtained by experiments have been presented.

Method for Attenuation of Gamma Rays

In gamma rays spectroscopy, one is most commonly interested only in the fraction of the monoenergic photons that have been penetrated the layer without any interaction and therefore has their original energy and direction. The term “attenuation” refers to the remaining photons that have either been absorbed or scattered in the layer.

When gamma rays transverse a small thickness of matter dx at any point in a medium, the extent of the photons is proportional to the radiation intensity at that point and to the thickness transverse

$$\frac{dI}{I} = -\mu dx \tag{1}$$

Where I is the intensity, e.g., in photon per m^2 per sec, and μ is the proportionality constant, usually expressed in m^{-1} units.[3]

The sum of this proper ability of occurrence per unit path length that the gamma rays photon is removed from the beam.

$$\mu = \mu \text{ (photoelectric)} + \mu \text{ (Compton)} + \mu \text{ (pair)}$$

and is called the linear attenuation coefficient of the absorber for the given radiation.

If a collimated beam of monoenergetic gamma rays of intensity I_0 passes through a thickness x of absorber, the intensity I_x of the emerging photons which have not suffered any interaction is obtained by integration of equation, the result is

$$\ln \frac{I_x}{I_o} = -\mu x \tag{2}$$

$$I_x = I_0 e^{-\mu x} \tag{3}$$

The intensity I_x defined in this matter is called the uncollided intensity or, more commonly, the uncollided flux, which emerges from the absorber. [4]

As the materials are composed of various elements, it is assumed that the contribution of each element of the compound to total photon interaction is additive, yielding the well-

known ‘mixture rule’ that represents the total mass attenuation coefficient of any compound as the sum of the appropriately weighted proportions of the individual atoms. Thus,

$$\left(\frac{\mu}{\rho}\right)_c = \sum_i W_i \left(\frac{\mu}{\rho}\right)_i \tag{4}$$

Where ρ is density, $\left(\frac{\mu}{\rho}\right)_c$ is the photon mass attenuation coefficient for the compound, $\left(\frac{\mu}{\rho}\right)_i$ is the photon mass attenuation coefficient for the individual elements in the compound, and W_i is the fractional weight of the elements in the compound.

The total mass attenuation coefficients can be used to determine the total atomic cross-section by the following relation,

$$\sigma_a = \frac{(\mu/\rho)_c}{N_A \sum_i \frac{W_i}{A_i}} \tag{5}$$

Where N_A is the Avogadro’s number and Ai is the atomic weight of the constituent element. Similarly, the average electronic cross-section, is given by

$$\sigma_{el} = \frac{1}{N_A} \sum_i f_i \frac{A_i}{Z_i} \left(\frac{\mu}{\rho}\right)_i \tag{6}$$

where σ_{el} is average electronic cross-section, $f_i = \left(\frac{n_i}{\sum_j n_j}\right)$ is the fractional abundance and Z is atomic number respectively of the constituent element. Here, n_i is the total number of atoms of the constituent element and $\sum_j n_j$ are the total number of atoms of all types present in the compound as per its chemical formula.

The concept of effective atomic numbers is introduced to describe the properties of these composite materials in terms of an equivalent element. The effective atomic number, Z_{eff} ,can now be written as[5],

$$Z_{eff} = \frac{\sigma_a}{\sigma_{el}} \tag{7}$$

Measurements

For all measurements cylindrical plastic container of inner diameter 6cm was used to put compound samples. The type of samples were mainly studied some thermoluminescent dosimetric compounds . These samples were obtained from local market. The grade of the collected samples is AnalaR. The weight of the plastic container was first recorded by using digital balance capable of weighing up to a fraction of a milligram. Sample was filled in the container up to 0.5cm thickness. Then, each sample prepared was weighed to calculate the density of the sample.

The experimental setup mainly consists of an Ortec 3"x3" NaI (Tl) crystal scintillation detector, spectroscopy amplifier (Model-671), multichannel analyzer (MCA) fitted in the computer and analyzing software (Gamma Vision-32) was used. The operating voltage of NaI (Tl) scintillation detector is 800V. In the experiment set up, the source, sample and detector are arranged vertically. The radioactive sources ^{22}Na, ^{133}Ba, ^{137}Cs and^{60}Co were used in the present investigation. Each γ-ray of energy 81keV, 356keV, 511keV, 662keV, 1173keV, 1274keV and 1332keV emitted by the above radioactive isotopes were collimated and detected. To reduce possible background radiation that comes from our environment, lead shielding was used in this measurement.

Results and Discussion

The gamma-energy spectrum for $BaSO_4$ and $CaSO_4$ are shown in Figure. 1(a) to Figure.1(h). From these experimental results, the linear attenuation coefficient and mass attenuation coefficients are calculated by using equation (3) and equation (4). These values are tabulated in Table (1). The variation of mass attenuation coefficients μ_m of compounds considered with different energy is shown in Figure (2). As energy increases, mass attenuation coefficient decreases, which is well known fact that the mass attenuation coefficient strongly depends on the atomic number of the absorber and inversely proportional to the energy.

Using the mass attenuation coefficients, the mean values of the atomic cross-section, also called the effective atomic cross-section in barn per atom were determined. These values are listed in Table (2). The variation of effective atomic cross-sections of compound samples with gamma ray energy is presented in Figure (3). This figure shows that the effective atomic cross-section decreases with increasing gamma ray energy.

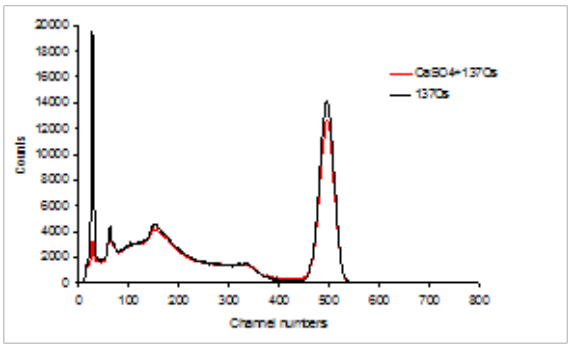

Figure (a): Gamma energy spectrum of ^{137}Cs with and without $CaSO_4$ compound

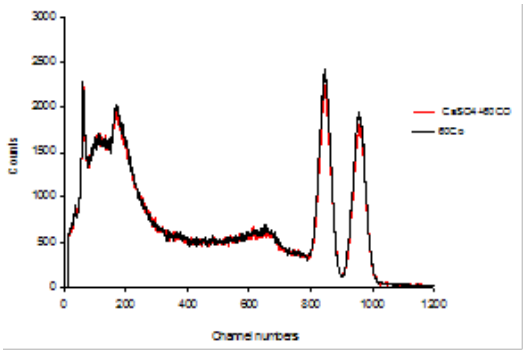

Figure (b): Gamma energy spectrum of ^{60}Co with and without $CaSO_4$ compound

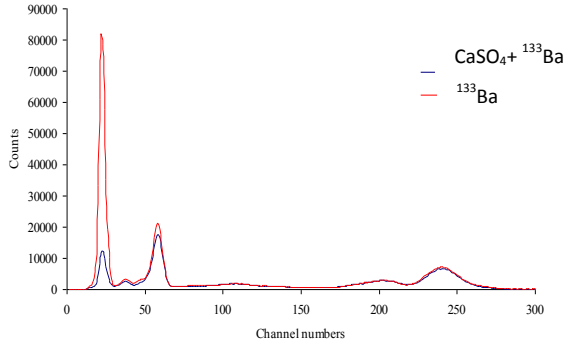

Figure (c): Gamma energy spectrum of ^{133}Ba with and without $CaSO_4$ compound

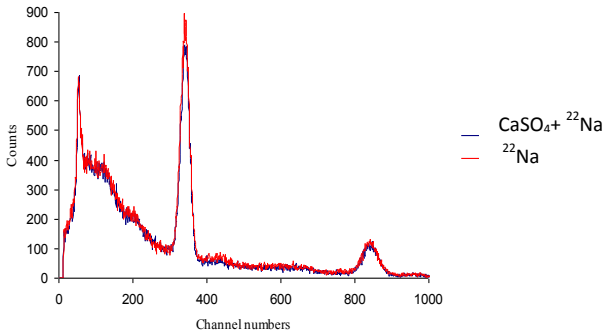

Figure (d): Gamma energy spectrum of ^{22}Na with and without $CaSO_4$ compound

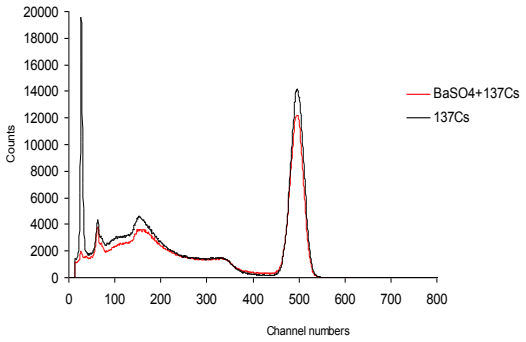

Figure (e): Gamma energy spectrum of ^{137}Cs with and without $BaSO_4$ compound

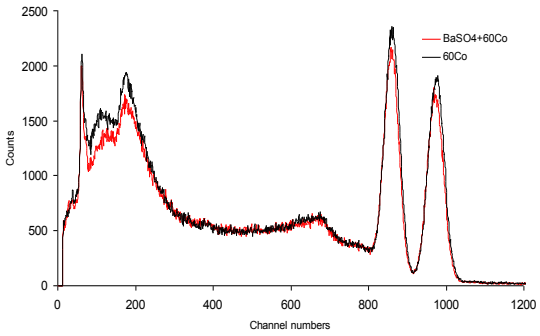

Figure (f): Gamma energy spectrum of ^{60}Co with and without $BaSO_4$ compound

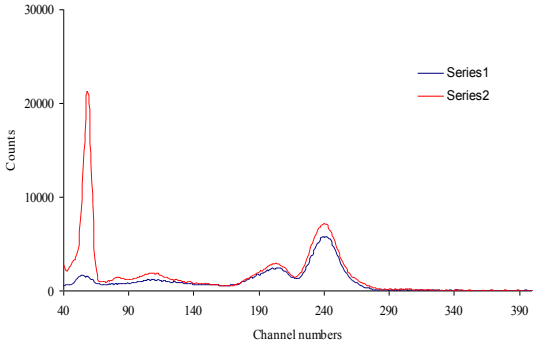

Figure (g): Gamma energy spectrum of ^{133}Ba with and without $BaSO_4$ compound

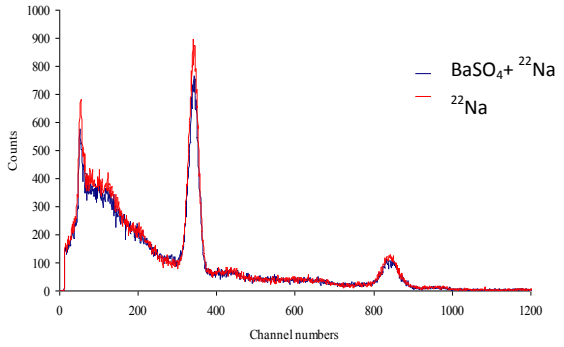

Figure (h): Gamma energy spectrum of ^{22}Na with and without **B**aSO_4 compound

Table (1): Experimentally measured values of photon mass attenuation coefficients for compound samples

Energy (keV)	Linear attenuation coefficient (cm^{-1})		Mass attenuation coefficient (cm^2g^{-1})	
	$BaSO_4$	$CaSO_4$	$BaSO_4$	$CaSO_4$
81	3.2788±0.0523	0.5447±0.0027	1.1749±0.0187	0.3245±0.0016
356	0.5385±0.0028	0.3153±0.0016	0.1929±0.0010	0.1878±0.0009
511	0.2611±0.0013	0.1615±0.0008	0.0935±0.0005	0.0963±0.0005
662	0.2199 ± 0.0005	0.1331 ± 0.0002	0.0788 ± 0.0002	0.0793 ± 0.0001
1173	0.1574 ± 0.0012	0.0993 ± 0.0009	0.0564 ± 0.0004	0.0592 ± 0.0006
1274	0.15002±0.0037	0.09705±0.0024	0.0537±0.0013	0.0578±0.0014
1332	0.1450 ± 0.0012	0.0919 ± 0.0007	0.0519 ± 0.0004	0.0548 ± 0.0004

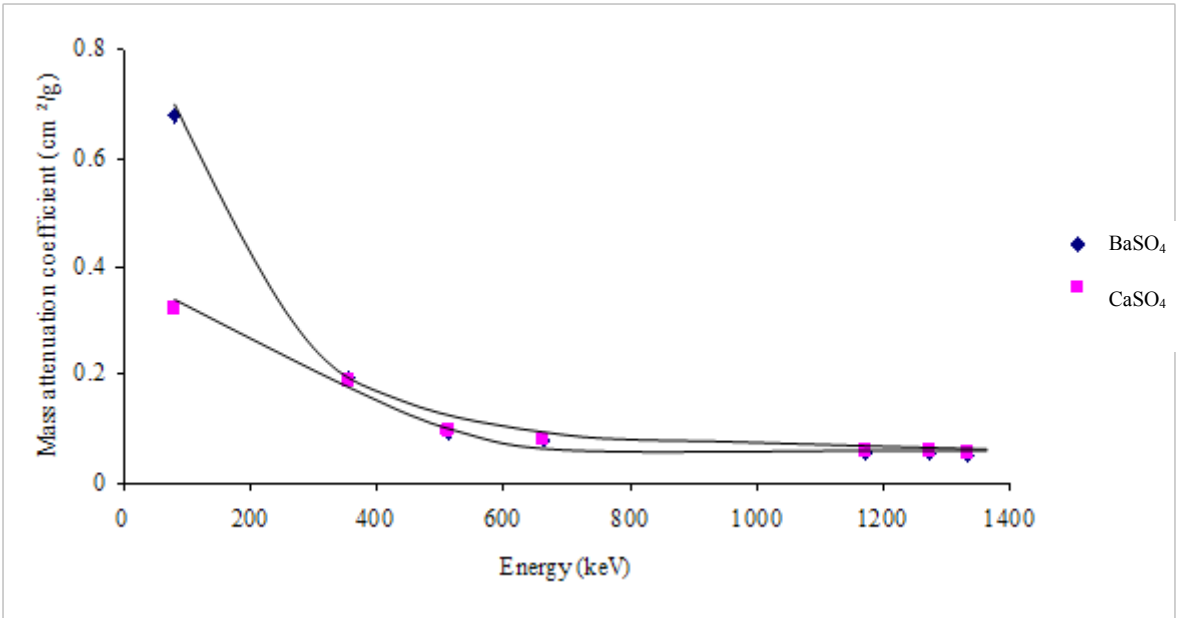

Fig (2): The variation of mass attenuation coefficients with different γ-ray energy

Table (2): Effective atomic cross-sections of compound samples

Energy (keV)	Effective atomic cross-section(b/atom)	
	$BaSO_4$	$CaSO_4$
81	75.7549±0.0194	12.2169±0.0091
356	12.4377±0.0209	7.0704±0.0051
511	6.0295±0.0046	3.6252±0.0049
662	5.0776±0.0017	2.9840±0.0013
1173	3.6339±0.0043	2.2292±0.0055
1274	3.4624±0.0096	2.1768±0.0079
1332	3.3489±0.0042	2.0627±0.0044

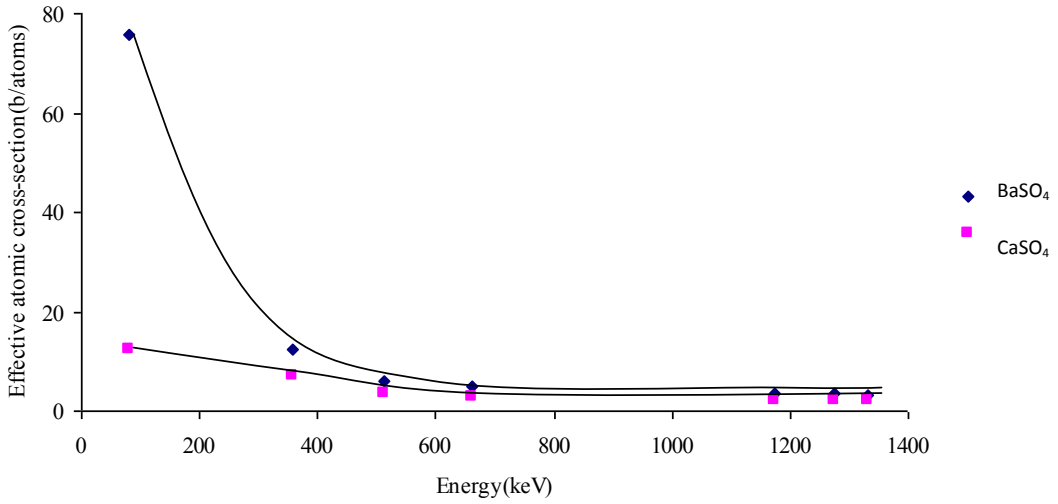

Fig (3): The variation of effective atomic cross-section with different γ-ray energy

Estimation of Effective Atomic Number

The effective atomic number for each sample was determined by using the effective atomic cross-section. These values are shown in Table (3). It is found that effective atomic number for each of the compounds considered is not constant but varies with photon energy. The variation of effective atomic number obtained with energy for the substance considered in this work is presented in Figure (4). It is clear that the behaviors of with energy for the compound are decreased as energy increases.

The effective atomic number varies from 11.2228 to 15.4312 for $CaSO_4$ and from 18.0343 to 95.9165 for $BaSO_4$. The upper and lower limit of for each of the considered materials was found to be dictated by the atomic numbers of the constituent elements of the materials. These variations may be attributed to the photon interaction dominating at the energy considered.

The highest value of the effective atomic number of the compounds was obtained at low energy. This is due to the fact that at low energy the photoelectric absorption coefficient is dependent on the highest power of the atomic number.

At the intermediate energies where Compton scattering dominates, the interaction mode is dependent on a unit power of the atomic number. Thus the value of the effective atomic number for each compound is almost constant. This is due to the fact that at the energy region where in the Compton scattering is the dominant mode of photon interaction.

Table (3): Effective atomic number of compound samples

Energy (keV)	Effective atomic number (Z_{eff})	
	$BaSO_4$	$CaSO_4$
81	95.9165±2.2778	15.4312±0.0332
356	34.4716±0.1117	14.4293±0.0380
511	19.8273±0.0425	12.6357±0.0313
662	18.6062±0.0162	11.4991±0.0067
1173	18.3071±0.0581	11.3675±0.0447
1274	18.0616±0.1323	11.2322±0.0928
1332	18.0343±0.0542	11.2228±0.0341

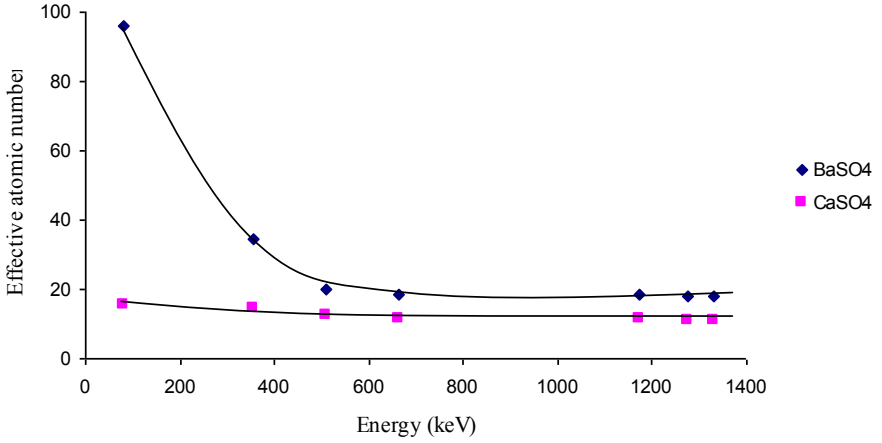

Fig (4): The variation of effective atomic number with different γ-ray energy

Conclusion

In the present work, the effective atomic cross-section values and effective atomic number of the thermoluminescent dosimetric compounds, Barium Sulphate ($BaSO_4$) and Calcium Sulphate ($CaSO_4$) were obtained using their mass attenuation coefficients in the photon energy 81,356,511, 662, 1173, 1274 and 1332keV. The highest value of the effective atomic number of the compounds was observed at low energy. The variations of effective atomic number with photon energy for the compounds were dictated by photon interaction processes. For the use of dosimetric material, effective atomic number should be evaluated for energy range of interest and not assumed to be constant.

Acknowledgement

The authors are thankful to Dr Maung Thin, Rector, University of Mandalay, for his permission and encouragement to conduct this research work.

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