

Full Length Research Paper

# Determination of mass attenuation coefficients for natural minerals from different places of Turkey

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**The mass attenuation coefficients ( $\mu_m$ ) for some natural minerals taken from different places of Turkey were measured at various low photon energies. The Am-241 radioactive source and Zr and Cd secondary exciter are used to get photons in the energy range 15.8 to 26.2 keV. For each sample and energy,  $I_0$  and  $I$  intensities which are without and after attenuation were measured by a Si(Li) detector coupled to multi channel analyzer (MCA) using narrow beam transmission arrangement and mass attenuation coefficients were determined using these intensities.**

**Key words:** Mass attenuation coefficient, natural mineral, transmission.

## INTRODUCTION

Celestine ( $\text{SrSO}_4$ ) is a mineral and has an orthorhombic system. Euhedral celestine crystal sizes change from 3 to 20 mm and often associate with the gypsum, anhydrite, and halite. Clinocllore ( $\text{Mg}_5\text{Al}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8$ ) is a kind of mica group mineral. The clinocllore crystals have monoclinic (or pseudo hexagonal) system with transparent to translucent habit (sometimes pale green) and enlarged crystal size change from 3 to 6 cm. Colemanite ( $\text{CaB}_3\text{O}_4(\text{OH})_3 \cdot \text{H}_2\text{O}$ ) is a secondary borate mineral that forms by alteration of borax and ulexite. It is a monoclinic, fibrous and euhedral crystal (2 to 4 cm) and found in evaporate deposits of alkaline lacustrine environments. Colemanite crystals may be colorless or white color, milky white, pale yellow, and gray. Extensive deposits of colemanite with about one billion tons reserves are in Turkey. Fluorite ( $\text{CaF}_2$ ) has isometric habit

with green color. Subhedral fluorite crystal sizes change from 2 to 7 mm. Garnet (Almandine) ( $\text{Fe}^{2+}_3\text{Al}_2(\text{SiO}_4)_3$ ) is a species of mineral belonging to the garnet group (isometric system). Crystals used in this study have euhedral form. Their sizes change from 1 to 2 cm and come from Dereli, Giresun. Gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) is a very soft mineral with monoclinic system and extensive evaporate beds in association with sedimentary rocks. Gypsum is a very soft mineral composed of calcium sulfate dehydrate, common in evaporate bed, sedimentary rocks, lake and sea water, hot springs, volcanic vapors, and sulfate solutions veins. There are a large number of uses for gypsum and some of these are drywall, plaster ingredient, plaster of paris, blackboard chalk, fertilizer and soil conditioner. Sizes of present gypsum change from 3 to 7 cm. Natrolite ( $\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10} \cdot 2\text{H}_2\text{O}$ ) is a tectosilicate mineral species belonging to the zeolite group. It has orthorhombic system. Natrolite mineral samples used in this study are single crystals with euhedral forms. Phlogopite ( $\text{KMg}_3\text{AlSi}_3\text{O}_{10}(\text{F},\text{OH})_2$ ) has monoclinic system. Euhedral

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crystals sizes change from 2 to 8 mm and has greenish or reddish-brown color. Vesuvianite ( $\text{Ca}_{10}\text{Mg}_2\text{Al}_4(\text{Si}_2\text{O}_7)_2(\text{SiO}_4)_5(\text{OH})_4$ ) also known as idocrase, is a green, brown, yellow, or blue silicate mineral. Vesuvianite occurs as tetragonal crystals in skarn deposits and limestone that have been subjected to contact metamorphism. The euhedral vesuvianite crystals used this study sizes changes from 1 to 6 cm.

When radiation passes through any matter, its intensity progressively reduces as a consequence of a complex series of interactions between radiation and atoms of the attenuating medium. The linear attenuation coefficient ( $\mu \text{ cm}^{-1}$ ) is defined as the probability of a radiation interacting with a material per unit path length (Woods, 1982) and it is related mass attenuation coefficient ( $\mu_m = \mu/\rho \text{ gcm}^{-2}$ ). The  $\mu_m$  is a measure of the average number of interactions that occur between photons and matter mass per unit area. The knowledge of natural minerals' physical parameters such as the  $\mu_m$  is useful for understanding their physical properties. Since the  $\mu_m$  values are important in fundamental physics and many applied fields, the accurate  $\mu_m$  values for X- and  $\gamma$ -rays in several materials are essential for some fields such as nuclear and radiation physics, radiation dosimetry, biological, medical, agricultural, environmental and industrial. Recently, a great number experimental investigations have been performed to determine the  $\mu_m$  and related parameters for various materials such as elements (Rettschlag et al., 2007), compounds (Sharanabasappa et al., 2009), tissue equivalent compounds (Parthasaradhi et al., 1992), mixtures (Jackson and Hawkes, 1981), alloys (El-Kateb et al., 2000; Han and Demir, 2009a, b, c, 2010), crystals (Demir and Han, 2009; Medhat, 2011), superconductor and semiconductor (Çevik et al., 2006; Baltaş et al., 2007), minerals (Han et al., 2009), glasses (Singh et al., 2002, 2008) radiation shielding materials (Medhat, 2009; Gencil, 2009; Gencil et al., 2010; Akkurt et al., 2010) building materials (Akkurt et al., 2009, Kirdsiri et al., 2011) biologically important materials (Khudzari et al., 2011) etc. at different photon energies. The comprehensive review of the literature showed that a great number experimental investigations have been performed to determine the  $\mu_m$  values for various materials such as elements, compounds, mixtures, alloys, crystals, superconductor and semiconductor etc. at different photon energies. However, in the literature, there are almost no reports on the study of  $\mu_m$  measurements for present natural minerals at present energies. This prompted us to carry out this work. In the present work, the  $\mu_m$  values of some natural minerals at 15.8, 17.7, 23.1 and 26.2 keV photon energies have been experimentally measured. The natural minerals were

irradiated with Zr and Cd secondary source with an Am-241 radioactive annular source using transmission arrangements. The variation of  $\mu_m$  versus photon energy is graphically presented.

## THEORY AND EXPERIMENTAL PROCEDURE

The linear attenuation coefficient of a material can be measured experimentally using the application of Lambert–Beer's law with standard transmission method by adopting narrow beam geometry. This process is described by the following equation:

$$I = I_o e^{-\mu_m t} \quad (1)$$

and

$$\mu_m = \frac{\ln(I_o/I)}{t} \quad (2)$$

where  $I_o$  and  $I$  are the un-attenuated and attenuated photon intensities,  $\mu_m = \mu/\rho$  ( $\text{cm}^2/\text{g}$ ) is the mass attenuation coefficient and  $t$  ( $\text{g}/\text{cm}^2$ ) is sample mass thickness (the mass per unit area).

The total  $\mu_m$  values for materials composed of multi elements is the sum of the  $(\mu_m)_i$  values of each constituent element by the following mixture rule (Jackson and Hawkes, 1981)

$$\mu_m = \sum_i \omega_i (\mu_m)_i \quad (3)$$

where  $\omega_i$  is the proportion by weight and  $(\mu_m)_i$  is mass attenuation coefficient of the  $i$ th element. For a materials composed of multi elements, the fraction by weight is given by

$$\omega_i = \frac{n_i A_i}{\sum_j n_j A_j} \quad (4)$$

where  $A_i$  is the atomic weight of the  $i$ th element and  $n_i$  is the number of formula units.

The total experimental uncertainty of the measured  $\mu_m$  values (or linear attenuation coefficients) depends on the uncertainties of the evaluation of peak area of  $I_o$  (without attenuation) and  $I$  (after attenuation) intensities, mass thickness measurements and counting statistics and can be calculated using the propagation of error formula

$$\Delta(\mu/\rho) = (1/t) \sqrt{(\Delta I_o/I)^2 + (\Delta I/I)^2 + (\ln(I_o/I))^2 (\Delta t/t)^2} \quad (5)$$

$\Delta I_o$ ,  $\Delta I$  and  $\Delta t$  are the errors in the intensities and thickness of the

**Table 1.** The experimental and calculated mass attenuation coefficients,  $\mu_m$  ( $\text{cm}^2/\text{g}$ ) for natural minerals.

Natural mineral	Chemical formula	Province	15.8		17.7		23.1		26.2	
			Mass attenuation coefficients ( $\mu_m$ )							
			Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.
Celestine	$\text{SrSO}_4$	Akkaya Celestine deposit, Sivas	10.7	11.6	37.7	43.8	20.9	21.8	16.4	15.6
Clinochlore	$\text{Mg}_5\text{Al}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8$	Kop Mountains, Erzincan	5.73	4.07	4.36	2.92	2.21	1.40	0.72	1.02
Colemanite	$\text{CaB}_3\text{O}_4(\text{OH})_3 \cdot \text{H}_2\text{O}$	Kestelek, Bursa	6.10	6.13	5.17	4.42	2.61	2.12	1.73	1.52
Fluorite	$\text{CaF}_2$	Keban, Elazığ	14.0	14.4	10.1	10.3	4.75	4.81	5.29	3.39
Garnet	$\text{Fe}^{2+}_3\text{Al}_2(\text{SiO}_4)_3$	Dereli, Giresun	14.6	19.7	10.2	14.2	4.85	6.74	5.05	4.77
Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	Aşkale, Erzurum	9.21	9.44	6.49	6.78	3.06	3.18	2.13	2.26
Natrolite	$\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10} \cdot 2\text{H}_2\text{O}$	Kop Mountains, Erzurum	6.62	4.27	3.40	3.06	1.57	1.46	1.02	1.06
Phlogopite	$\text{KMg}_3\text{AlSi}_3\text{O}_{10}(\text{F},\text{OH})_2$	Yıldızeli, Karakoç, Sivas	6.84	5.68	4.96	4.07	2.62	1.92	1.55	1.38
Sulphur	$\text{S}_8$	Keçiborlu, Isparta	13.3	13.4	9.94	9.59	4.32	4.42	4.83	3.10
Vesuvianite	$\text{Ca}_{10}\text{Mg}_2\text{Al}_4(\text{Si}_2\text{O}_7)_2(\text{SiO}_4)_5(\text{OH})_4$	Gümüşhane	11.1	10.3	8.05	7.38	3.38	3.45	2.24	2.45

Theo, Theory; Exp, experimental.

sample, respectively. Estimated error in the experimental measurement was approximate 3%. The secondary X-ray sources were irradiated by 59.5 keV photons emitted by an Am-241 radioactive source. 15.8 keV (Zr  $K\alpha$ ), 17.7 keV (Zr  $K\beta$ ), 23.1 keV (Cd  $K\alpha$ ) and 26.2 keV (Cd  $K\beta$ ) energies were obtained using Zr and Cd as a secondary target. The samples were placed individually between the secondary source and the detector. For each sample and energy,  $I_0$  and  $I$  intensities which are without and after attenuation were measured by a Si(Li) detector. The peak areas have been calculated from the spectrum obtained for each measurement. The measurements for all types of samples were carried out five times for each energy value.

## RESULTS

The experimental mass attenuation coefficient ( $\mu_m$ ) values for 10 natural minerals from Turkey at various low photon energies have been shown in Table 1 together with some properties of natural minerals. Figure 1 is drawn for graphical presentation of  $\mu_m$  values of natural minerals in

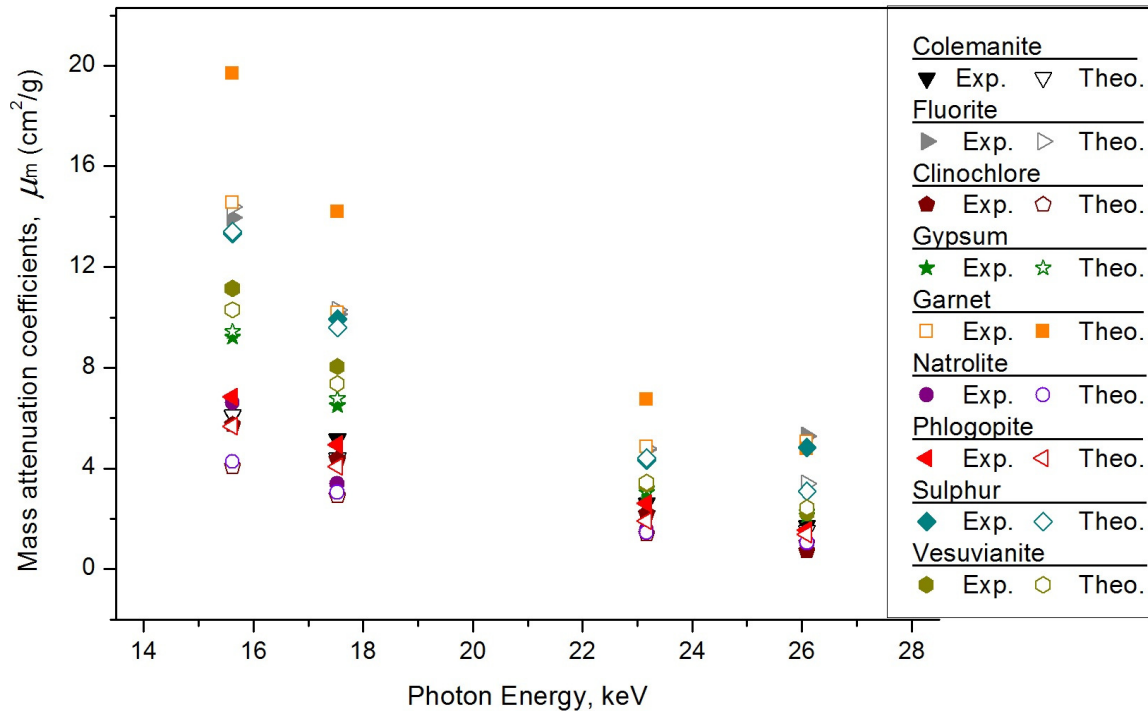
Table 1 and shows change of  $\mu_m$  values as a function of photon energies. It is clearly seen that the  $\mu_m$  values for present natural minerals depends on the photon energy and generally decreases with increasing photon energy. The total experimental uncertainty of the  $\mu_m$  values depends on the uncertainties of  $I_0$  (without attenuation) and  $I$  (after attenuation) peak area evaluation, mass thickness measurements and counting statistics. Typical total uncertainty in the measured experimental  $\mu_m$  values is estimated to be ~3%. In the composite materials, the interaction (such as absorption and scattering) of  $\gamma$ - and X-rays with these materials is related to various parameters such as photon energies and density of materials etc.

The present experimental study has been undertaken to get some information on the  $\mu_m$  for natural crystal. In the interaction of photon with

matter,  $\mu_m$  values are dependent on the physical and chemical environments of the sample. The obtained  $\mu_m$  values decrease with increasing photon energy.

## Conclusion

In the present study, it is indicated that the  $\mu_m$  values are useful parameters for natural crystals. The results of this study will be helpful to understand better how  $\mu_m$  values change with variation of composition and/or density etc properties of natural crystal. To the best of our knowledge, experimental investigation of the  $\mu_m$  for present natural crystals in these energies are not available in the literature. Moreover, the results of this work can stimulate both experimental and theoretical research for present and other crystals and minerals in various energies.



**Figure 1.** Variation of mass attenuation coefficients ( $\mu_m$ ) as a function of photons energies.

## REFERENCES

- Akkurt I, Akyıldırım H, Mavi B, Kilincarslan S, Basyigit C (2010). Photon attenuation coefficients of concrete includes barite in different rate. *Ann. Nucl. Energy*, 37: 910-914.
- Akkurt I, Kilincarslan S, Basyigit C, Mavi B, Akyıldırım H (2009). Investigation of photon attenuation coefficient for pumice. *Int. J. Phys. Sci.*, 4: 588-591.
- Baltas H, Celik S, Cevik U, Yanmaz E (2007). Measurement of mass attenuation coefficients and effective atomic numbers for MgB<sub>2</sub> superconductor using X-ray energies. *Radiat. Meas.*, 42: 55-60.
- Cevik U, Baltas H, Celik A, Bacaksız E (2006). Determination of attenuation coefficients, thicknesses and effective atomic numbers for CuInSe<sub>2</sub> semiconductor. *Nucl. Instrum. Methods, B* 247: 173-179.
- Demir L, Han I (2009). Mass attenuation coefficients, effective atomic numbers and electron densities of undoped and differently doped GaAs and In P crystals. *Ann. Nucl. Energy*, 36: 869-873.
- El-Kateb AH, Rizk RAM, Abdul-Kader AM (2000). Determination of atomic cross-sections and effective atomic numbers for some alloys. *Ann. Nucl. Energy*, 27: 1333-1343.
- Gencil O (2009). The application of artificial neural networks technique to estimate mass attenuation coefficient of shielding barrier. *Int. J. Phys. Sci.* 4: 743-751.
- Gencil O, Brostow W, Ozel C, Filiz M (2010). An investigation on the concrete properties containing colemanite. *Int. J. Phys. Sci.*, 5: 216-225.
- Han I, Demir L (2009a). Mass attenuation coefficients, effective atomic and electron numbers of Ti and Ni alloys. *Radiat. Meas.* 44: 289-294.
- Han I, Demir L (2009b). Studies on effective atomic numbers, electron densities from mass attenuation coefficients in Ti<sub>x</sub>Co<sub>1-x</sub> and Co<sub>x</sub>Cu<sub>1-x</sub> alloys. *Nucl. Instrum. Methods B.*, 267: 3505-3510.
- Han I, Demir L (2009c). Determination of mass attenuation coefficients, effective atomic and electron numbers for Cr, Fe and Ni alloys at different energies. *Nucl. Instrum. Methods B.*, 267: 3-8.
- Han I, Demir L (2010). Studies on effective atomic numbers, electron densities and mass attenuation coefficients in Au alloys. *J. X-Ray Sci. Technol.* 18: 39-46.
- Han I, Demir L, Sahin M (2009) Determination of mass attenuation coefficients, effective atomic and electron numbers for some natural minerals. *Radiat. Phys. Chem.* 78: 760-764.
- Jackson DF, Hawkes DJ (1981). X-ray attenuation coefficients of elements and mixtures. *Phys. Report* 70: 169-233.
- Khudzari JM, Wagiran H, Hossain MI, Ibrahim N, Agam MA (2011). Heavy metals Mn, Fe, Ni, Cu and Zn in human hair samples using energy dispersive X-ray fluorescence analysis. *Int. J. Phys. Sci.*, 6: 2090-2094.
- Kirdsiri K, Kaewkhao J, Chanthima N, Limsuwan P (2011). Comparative study of silicate glasses containing Bi<sub>2</sub>O<sub>3</sub>, PbO and BaO: Radiation shielding and optical properties. *Ann. Nucl. Energy* 38: 1438-1441.
- Medhat ME (2009). Gamma-ray attenuation coefficients of some building materials available in Egypt. *Ann. Nucl. Energy* 36: 849-852.
- Medhat ME (2011). Studies on effective atomic numbers and electron densities in different solid state track detectors in the energy range 1 keV–100 GeV. *Ann. Nucl. Energy* 38: 1252-1263.
- Parthasaradhi K, Esposito A, Pelliccioni M (1992). Photon attenuation coefficients in tissue equivalent compounds. *Int. J. Appl. Radiat. Isot.* 43: 1481-1484.
- Rettschlag M, Berndt R, Mortreau P (2007). Measurement of photon mass attenuation coefficients of plutonium from 60 to 2615 keV. *Nucl. Instrum. Methods A* 581: 765-771.
- Sharanabasappa, Kaginelli SB, Kerur BR, Anilkumar S, Hanumaiah B (2009). Mass attenuation coefficient of chromium and manganese compounds around absorption edge. *J. X-Ray Sci. Technol.* 17: 75-84.
- Singh K, Singh H, Sharma V, Nathuram R, Khanna A, Kumar R, Bhatti SS, Sahota HS (2002). Gamma-ray attenuation coefficients in bismuth borate glasses. *Nucl. Instrum. Methods B* 194: 1-6.
- Singh S, Kumar A, Singh D, Thind KS, Mudahar GS (2008). Barium-borate-flyash glasses: As radiation shielding materials. *Nucl. Instrum. Methods B* 266: 140-146
- Woods J (1982). *Computational Methods in Reactor Shielding*. Pergamon, New York.