SNRU Journal of Science and Technology

Journal home page :snrujst.snru.ac.th

Gamma-rays interaction study on calcite and quartz: Theoretical calculation

Tanasapon Preechayan[1, *], Wuttichai Chaiphaksa[2, 3], Jakrapong Kaewkhao[2, 3]

[1]Physics Program, Faculty of Science and Technology, Muban Chombueng Rajabhat University, Ratchaburi, 70150 Thailand

[2]Physics Program, Faculty of Science and Technology, Nakhon Pathom Rajabhat University, Nakhon Pathom, 73000 Thailand

[3]Center of Excellence in Glass Technology and Materials Science (CEGM), Nakhon Pathom Rajabhat University, Nakhon Pathom, 73000 Thailand

[*]**Corresponding Author**: wuttichai.chaiphaksa@gmail.com

Received :27 June 2017; **Revised:** 5 Februar 2018; **Accepted :**6 Februar 2018; **Available online :**1 May 2018

Paper selected from The 3rd International Conference on Applied Physics and Material Applications 2017 (ICAPMA 2017)

Abstract

Calcite and quartz gemstones samples were chosen in this paper for theoretical calculation on gamma rays interaction. The mass attenuation coefficient has been calculated by WinXCom program at energy range 1 keV – 100 GeV. The result show that, the mass attenuation coefficient of calcite and quartz samples depend on photon energy and decreases with increasing of the photon energy. Moreover, both samples shows discontinuities in the lower energy range which corresponds to photoelectric absorption edges of the Z elements. The partial interactions and the effective atomic number have been measured and it was found that the effective atomic number of calcite is higher than quartz. It was found that, the photoelectric interaction of both gemstone shows similar trend as that of coherent scattering at lower energy further it shows incoherent interaction in the energy range 80 – 10000 keV for calcite and 40 – 20000 keV for quartz. The similar trend was reflected in the pair production arising from nuclear and electron field in these gemstones.

Keywords: Calcite; Quartz; Mass attenuation coefficient; Effective atomic number

1. Introduction

Calcite and quartz are common natural gemstones and many countries have abundantly natural gemstone on earth. A natural gemstone is a mineral, stone, or organic matter that can be cut and polished or otherwise treated for use as jewelry or other ornament [1]. Nowadays, many natural gemstones use radiation (gamma-rays) techniques to improve quality [2]. These natural gemstones have different behaviors of absorbing radiation and affecting the color change. Therefore, the attenuation such as the mass attenuation coefficients, the partial interactions and including the effective atomic number of X-rays and gamma-rays which are useful for understanding the physical properties with matters [2]. There are many works have already been published about calcite and quartz but not extensive for the attenuation of gamma-rays interactions [3 – 5].

After Gerward et al. [6, 7] introduced the WinXCom program for calculating the mass attenuation coefficients of elements, compounds and mixtures materials. Then, many literatures reported the experimental and theoretical investigations on photon interaction in different materials [2, 8]. Korkut et al. [8] studied the mass attenuation coefficients of amethyst ore at different gamma-rays energies. Limkitjaroenporn and Kaewkhao [2] studied gamma-rays attenuation of zircons from Cambodia and South Africa at different energies with a new technique for identifying the origin of gemstone.

In this paper, the theoretical of the photon interaction properties of calcite and quartz have been studied. The mass attenuation coefficients, the effective atomic number and the partial interactions of both gemstones were investigated. WinXCom program was used for photon energies in the range of 1 keV – 100 GeV.

2. Materials and methods

The total attenuation coefficients for any chemical compound or homogeneous mixture of shielding materials are obtained as weighted sums over the corresponding coefficients for elements. The mass attenuation coefficients (μ / ρ) can be given by the following weighted summation [9]:

$$\mu / \rho = \sum_i w_i (\mu / \rho)_i \tag{1}$$

where ρ is the density of the sample and w_i and $(\mu / \rho)_i$ are the fraction by weight and mass attenuation coefficient of i_{th} constituent, respectively. The mass attenuation coefficients for total and partial interactions have been obtained from the WinXCom [7]. Equation 1, this well-known mixture rule is valid with the assumption that the effects of molecular binding and the chemical and crystalline environment are negligible. For a chemical compound, the fraction by weight is given by [9]:

$$w_i = \frac{a_i A_i}{\sum_j a_j A_j} \tag{2}$$

where a_i and A_i are the number of formula units and the atomic weight of the i_{th} element, respectively. The basic relation for calculating the effective atomic number (Z_{eff}) for all types of materials, compounds as well as mixtures can be written in terms of the fraction abundance as [10]:

$$Z_{eff} = \frac{\sum_i f_i A_i (\mu / \rho)_i}{\sum_j f_j \frac{A_j}{Z_j} (\mu / \rho)_j}, \tag{3}$$

where $f_i = n_i / \sum_j n_j$ is the fractional abundance of constituent element i (n_i is the number of atoms, $\sum_j n_j$ is the total number of atoms present in the molecular formula), A_i is the atomic weight and Z_i is the atomic number.

3. Results and discussions

General properties of calcite and quartz are shown in Table 1 and chemical composition of both gemstones expressed as wt% are shown in Table 2. The mass attenuation coefficients of quartz and calcite was calculated by WinXCom program at the energy range 1 keV – 100 GeV.

Table 1 General properties of calcite and quartz [1].

Properties	Quartz	Calcite
Hardness (moh's)	7	3
Density (g cm^{-3})	2.650	2.710
Refractive Index	1.54 – 1.55	1.49 – 1.74
Crystal System	Hexagonal	Hexagonal

Table 2 The chemical composition of calcite and quartz expressed as wt% [11].

Gemstones	SiO_2	CaO	Na_2O	K_2O	SO_3	MgO	P_2O_5	Fe_2O_3	Al_2O_3	TiO_2
Quartz	0.9926	0.0018	0.0003	0.0006	0.0001	0.0004	0.0001	0.0012	0.0026	0.0003
Calcite	0.0015	0.9965	-	0.00015	0.00025	-	0.0001	-	0.0015	-

From Fig. 1, the mass attenuation coefficient of calcite and quartz depend on photon energy and decreases with increasing of the photon energy. After the energy above 4 keV, the results show that of calcite higher values than quartz [7, 11].

For the partial interactions, the photoelectric interaction of calcite and quartz are shown in Fig. 2, which indicates that the photoelectric interaction decreases with increasing of photon energy. Moreover, the result show that, these values found to be the main interaction at energy range 1 – 50 keV for quartz and 1 – 70 keV for calcite. Furthermore, calcite and quartz at the low energies discontinuities correspond to photoelectric absorption edges of the Z elements. The result show that, quartz; the silicon K edge at 1.84 keV, calcite; the calcium K edge at 4.04 keV. Due to Si and Ca are the main chemical composition of quartz and calcite, respectively. The coherent scattering found to be significant at low photon energy and rapidly decreases with increasing of photon energy for both gemstone. For the incoherent interaction, the values found to be the main interaction at photon energy range 80 – 10000 keV for calcite and 40 – 20000 keV for quartz. The pair production of both gemstone is the main interaction at photon energy higher than 1022 keV.

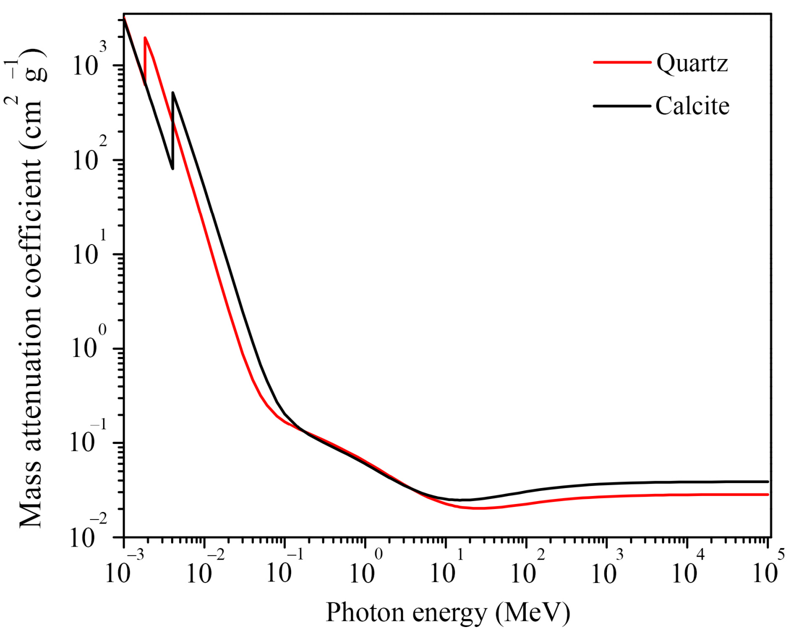

Fig. 1 Mass attenuation coefficient of calcite and quartz versus photon energy range 1 keV – 100 GeV

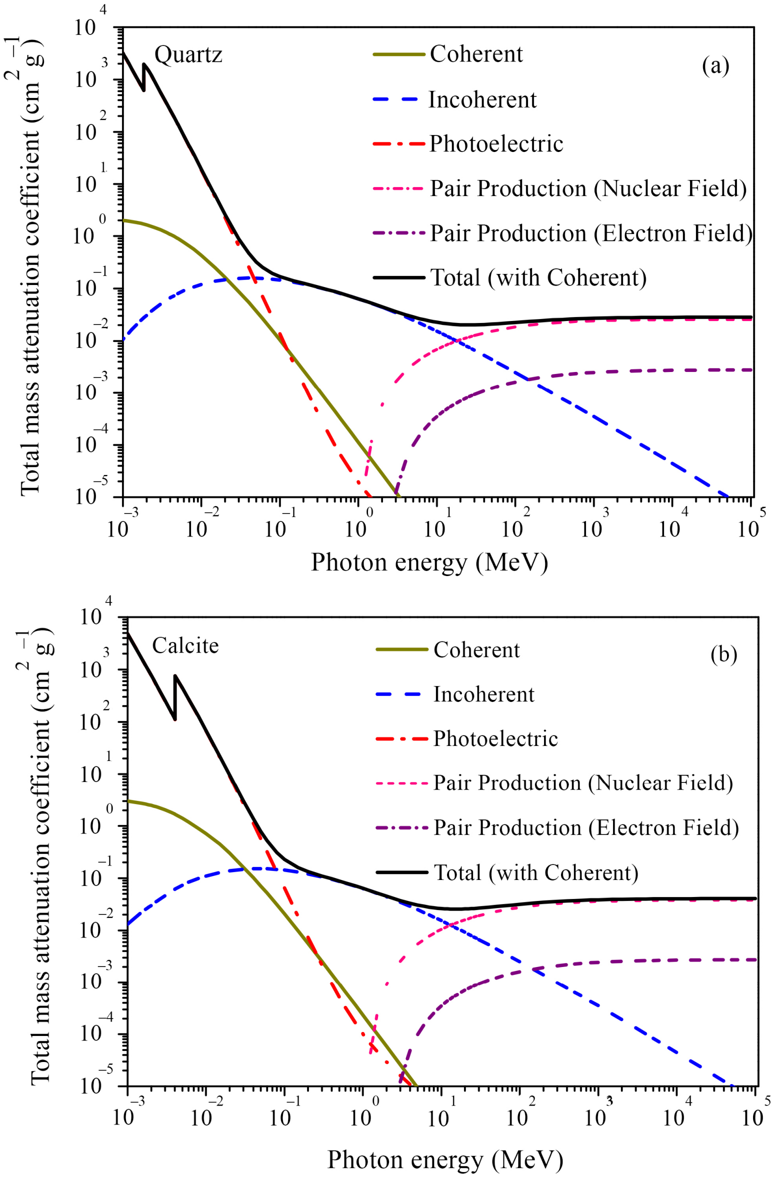

Fig. 2 Mass attenuation coefficient and partial interactions of (a) quartz (b) calcite versus photon energy range 1 keV – 100 GeV

The distinction of effective atomic number of calcite and quartz from energy ranging 1 keV – 100 GeV are shown in Fig. 3. At the photon energy lower than 10 keV, the result found that, the peak which corresponding with the photoelectric absorption edge of calcium K edge for calcite and silicon K edge for quartz. The value of effective atomic number of calcite higher than quartz of all photon energy range.

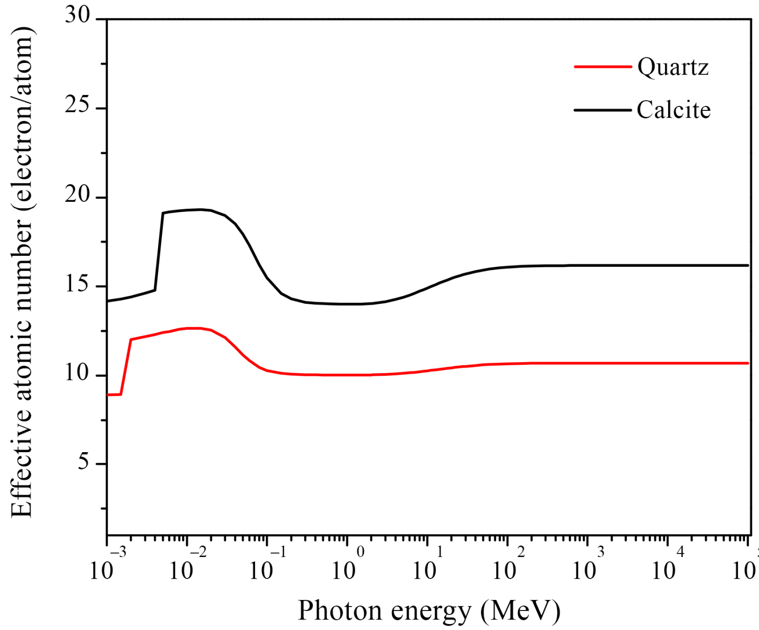

Fig. 3 Effective atomic number of calcite and quartz versus photon energy range 1 keV – 100 GeV

4. Summary

The theoretical study of mass attenuation coefficient, effective atomic number and partial interactions of calcite and quartz at photon energy range 1 keV – 100 GeV were successfully investigated. These gemstones were investigated using WinXCom program. It was found that, the mass attenuation coefficient of calcite and quartz depend on photon energy and decreases with increasing of the photon energy. The coherent scattering found to be significant at low photon energy and rapidly decreases with increasing of photon energy for both gemstone. The photoelectric interaction decreases with increasing of photon energy and at the low energies discontinuities correspond to photoelectric absorption edges of the Z elements. The pair production of both gemstone is the main interaction at photon energy higher than 1022 keV. The value of effective atomic number of calcite higher than quartz of all photon energy range.

5. Acknowledgement

The researcher would like to thank Muban Chombueng Rajabhat University for support this research. I would like to thank the Center of Excellence in Glass Technology and Materials Science (CEGM), Faculty of Science and Technology, Nakhon Pathom Rajabhat University for support facilities.

6. References

[1] S. Hutcheson, D. Morgan, C. Spears, U.S. Department of the Interior, United States, 2015.

[2] P. Limkitjaroenporn, J. Kaewkhao, Gamma-rays attenuation of zircons from Cambodia and South Africa at different energies: A new technique for identifying the origin of gemstone, Radiat. phys. and chem. 103 (2014) 67 – 71.

[3] S. Usha Padukone, K.A. Natarajan, Microbially induced separation of quartz from calcite using Saccharomyces cerevisiae, Colloids Surf., B. 88 (2011) 45 – 50.

[4] V.A. Tabrizy, R. Denoyel, A.A. Hamouda, Characterization of wettability alteration of calcite, quartz and kaolinite: Surface energy analysis, Colloids and Surfaces A: Physicochem. Eng. Aspects. 384 (2011) 98 – 108.

[5] M.G. Lioliou, C.A. Paraskeva, P.G. Koutsoukos, A.C. Payatakes, Heterogeneous nucleation and growth of calcium carbonate on calcite and quartz, J. Colloid Interface Sci. 308 (2007) 421 – 428.
[6] L. Gerward, N. Guilbert, K.B. Jensen, H. Levring, X-ray absorption in matter. Reengineering XCOM. Radiat. Phys. Chem. 60 (2001) 23 – 24.
[7] L. Gerward, N. Guilbert, K.B. Jensen, H. Levring, WinXCom-a program for calculation X-ray attenuation coefficients. Radiat. Phys. Chem. 71 (2004) 653 – 654.
[8] T. Korkut, H. Korkut, A. Karabulut, G. Budak, A new radiation shielding material: amethyst ore. Ann. Nucl. Energy. 38 (2011) 56 – 59.
[9] N. Chanthima, J. Kaewkhao, Calculation of mass attenuation coefficient and related parameters of Bao-SiO_2 glass system by WinXCom and FFAST, 38th Congress on Science and Technology of Thailand (STT38), Chiang Mai, Thailand. 17 – 19 October 2012, 73 – 78
[10] N. Chanthima, J. Kaewkhaoand, P. Limsuwan, Study of photon interactions and shielding properties of silicate glasses containing Bi_2O_3, BaO and PbO in the energy region of 1 keV to 100 GeV, Ann. Nucl. Energy. 41 (2012) 119 – 124.
[11] N. Kouras, A. Harabi, F. Bouzerara, L. Foughali, A. Policicchio, S. Stelitano, F. Galiano, A. Figoli, Macro-porous ceramic supports for membranes prepared from quartz sand and calcite mixtures, J. Eur. Ceram. Soc. 37 (2017) 3159 – 3165.