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PHOTON INTERACTION PARAMETERS OF SOME CHEMICAL COMPOUNDS FOUND IN HARD TISSUE

Didar Swara Salih Mrs.
Department of Physiotherapy,Erbil Health Technical College, Erbil Polytechnic University,
didar.salih@epu.edu.iq

Rafet Y Mr.
Department of Physics, Faculty of Science, Van Yüzüncü Yıl University,Turkey

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Abstract

Photon interaction parameters of some chemical compounds in hard tissue were investigated in the energy range (1keV-100 GeV) by using the (NistXCom) program. These interaction parameters: mass attenuation coefficients (μρ), effective atomic number (Zeff), and electron density (Nel) as a measure of the absorption of photon energy by compounds in hard tissue. The events that cause absorption are the photoelectric effect, Compton effect, and pair formation events. Effective atomic numbers and electron densities of some compounds in hard tissue were calculated using the obtained mass attenuation coefficients. From the obtained data, the values of photon interaction parameters have been investigated to change with energy and compounds of the hard tissue. The variations of these parameters with energy are shown graphically for all photon interactions. Also, we calculated the half-value thickness (HVT) and μρ for some compounds Al_2O_3, SiO_2 and MgO are agree with the theoretical value.

Keywords

Mass attenuation coefficients, Effective atomic number, Electron density, Half value thickness, Hard tissue.

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RESEARCH ARTICLE

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Didar S. Salih*[,1], Rafet Y[1]
*Department of Physiotherapy,Erbil Health Technical College, Erbil Polytechnic University,
[1]Department of Physics, Faculty of Science, Van Yüzüncü Yıl University,Turkey.

***Corresponding author:**
Didar S.Salih, Department of Physiotherapy,Erbil Health Technical College, Erbil Polytechnic University, Erbil, Kurdistan Region, Iraq.
E-mail: didar.salih@epu.edu.iq

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ABSTRACT

Some chemical compounds' photon interaction parameters in hard tissue were investigated by using the (NistXCom) program in the energy range (1keV-100 GeV). The following interaction parameters are included: mass attenuation coefficients (μρ), effective atomic number (Zeff), and electron density (Nel). Those are all photon energy absorption measures by compounds in hard tissue. The Compton effect, the photoelectric effect, and pair creation events are all phenomena that induce absorption. (Zeff), and (Nel) were calculated using the (μρ) of certain substances in hard tissue. The parameters of photon interaction values have been explored to see how they alter with energy and hard tissue constituents. For all photon interactions, the fluctuations of these parameters with energy are graphically shown. We also estimated the half value thickness (HVT), which agrees with theoretical values for several compounds including Al2O3, SiO2, and MgO.

Keywords: (μρ), Electron density, (Zeff), (HVL), Hard tissue.

INTRODUCTION

Today, human beings are constantly exposed to radiation due to the use of developing technology in their lives. Radiation is electromagnetic waves consisting of packets of photons. Due to the negative effects of these electromagnetic waves on living things, they cause some discomfort. It is important to know and investigate the photon interaction parameters of chemical compounds in biological structure in order to eliminate these disorders. Because of these, recent research has focused on studying matter and photon interaction phenomena. Because, it aims to both protect from radiation and improve its use and benefit in medicine.(Xiangjie et al.,2022). It is to find the material with better radiation absorption properties of the materials used to protect the environment we are in from radiation more safely. For this reason, the selection of materials for protection from radiation gains importance. At the same time, high-energy photons are employed in medicine for therapy and diagnostics. (Akça and Erzeneoğlu, 2014; Böke,2014). For this reason, it is crucial to understand the mass absorption characteristics of the chemical compounds within organs of the human body and other related interaction parameters. These parameters include (μ_ρ), (Z_{eff}) and (N_{el}).

The coefficient of mass attenuation (μ_ρ) may be defined as a measure of photon energy absorption by matter. The events that cause absorption are the Compton effect, the photoelectric effect, as well as pair formation events. Although Z_{eff} characterizes the interaction of matter with radiation, it is also of great importance in radiation biology, medical physics, and radiography and radiation dosimetry. (Demir & Turşucu, 2012; Gowda et al., 2005). The same considerations can be made for electron density (N_{el}) as for active atomic atoms.

Researchers who have made important research in the literature on coefficients of mass attenuation and interaction parameters have stated that the atomic numbers of composite materials interacting with photons do not have a single value. (Hine, 1952; Creagh, 1987; Hubbel and Seltzer, 1995; Guru et al., 1998). This means that its value depends on the photon energy. Initially, XCOM

code program (Berger and Hubbel, 1999) and WinXCom program developed by Gerward et al. ,2001; Gerward et al., 2004). were used to determine (μ_ρ) Manohara et al (2008) developed important basic formulas on interaction parameters.

In this study, interaction parameters of some chemical compounds (CaO, P_2O_5, MgO, SiO_2, Fe_2O_3 and Al_2O_3) in hard tissue in the photon energy range were computed. From these parameters, mass reduction coefficients (μ_ρ) were determined using the NistXcom in the 1 keV - 100 GeV energy range. Based on the results, the (Z_{eff}) and density of electrons (N_{el}) for the compounds were calculated using the total interaction (μ_ρ). Experimentally measured half value thickness (HVT) and μ_ρ for some compounds (Al_2O_3, SiO_2 and MgO) by using X-ray device (554800).

MATERIALS AND METHODS

1.Method of calculation

NistXCom were used to calculate photo interaction parameter of partial photon such as the effects mass reduction coefficients, atomic photoelectric event, Pair formation, incoherent scattering, and coherent scattering of any compound in hard tissue at 1 keV-100 GeV range energy. Scattering and absorption reduce photon energy traveling through materials. Absorption-induced attenuation follows the Beer–Lambert's law,

$$I = I_0 e^{-\mu x} = I_0 e^{-(\mu/\rho)d} \qquad (1)$$

where I and I_o are the photon intensities before and after attenuation, d denotes the mass per unit area (g/cm^2) and μ/ρ is the (μ_ρ) (cm^2 /g). The (μ_ρ) values for any element and complex materials are determined using the mixing rule by the NistXCom program code. with energies ranging from 1 keV to 100 GeV.

$(\mu/\rho)_C$: The photon mass attenuation coefficient of components.

$$(\mu/\rho)_C = \sum w_i (\mu/\rho)_i \qquad (2)$$

The component element's weight fraction and photon mass attenuation coefficient are w_i and $(\mu/\rho)_i$ respectively. The fraction by weight (w_i) of a chemical substance is given by,

$$w_i = \frac{n_i A_i}{\sum n_j A_j} \qquad (3)$$

Ai: The ith element's atomic weight and Ni: The number of formula units.

The following equation 4 yields total molecular cross-section values (m, barns/molecule).

$$\sigma_m = \frac{(\mu/\rho)_C}{N_A} M \qquad (4)$$

$$M = \sum n_i A_i \qquad (5)$$

M: Molecular weight, NA: Avagadro number, and Ni: Number of atoms in the ith element. σ_a:Total atomic cross-sections and σ_e, : electronic cross-sections are calculated using the formulae below.

$$\sigma_a = \frac{\sigma_m}{\sum n_i} \qquad (6)$$

$$\sigma_e = \frac{1}{N_A} \sum \frac{A_i}{Z_i} f_i \ \mu_i \qquad (7)$$

Where Zi: atomic number and fi: fractional abundance.

$$f_i = \frac{n_i}{\sum n_i} \qquad (8)$$

The component element has ni atoms. The (Z_{eff}) is defined as the ratio of the σ_a and σ_e. (Z_{eff}) of the whole photon interaction may be calculated as follows: Also, from Eq. (9 and 10) can be calculated Z_{eff}.

$$Z_{eff} = \frac{\sigma_a}{\sigma_b} \qquad (9)$$

$$Z_{eff} = \frac{\sum_i f_i A_i \mu_i}{\sum_j f_j \frac{A_j}{Z_j} \mu_j} \qquad (10)$$

The change in Z_{eff} can be calculated by using photoelectric, Compton, pair production attenuation coefficients instead of total μ_i. Thus, the effect of the three factors on the change in Z_{eff} can be seen separately. The following formula may be used to compute the electron density, N_{el} (the number of electrons per unit mass, electron/g):

$$N_{el} = N_A \frac{Z_{eff}}{\langle A \rangle} \qquad (11)$$

$\langle A \rangle$: Compound's average atomic mass.

2.Experimental set up

The Compton Scattering Experiment involves the fundamental understanding of the interaction of radiation with matter. It involves an understanding of the photoelectric effect, the Compton Effect, and Pair Production. It also involves an understanding of x-rays and radiation decay schemes.

An x-ray generator in the laboratory that uses a Molybdenum anode target as an x-ray radiation source, as well as a sample container, were utilized to calculate the μ. The sample is put at a distance of 150 mm from the X-ray tube. The system is known as (X-ray apparatus 554 800).

The linear attenuation coefficient was measured using samples as show Fig (1) and Table (1) show all information about the target.

Figure 1: Some chemical compouds target to calculate half value thickness experimentally

RESULTS AND DISCUSSION

The μ_ρ of some compounds in hard tissue were calculated using the Nist XCOM program are given in Fig. (2- 3) With increased energy, the mass attenuation coefficients drop. it is agreed with (Hamideen et al., 2022).

Generally, in photoelectric events up to in the energy region 0.1 MeV, Compton up to 10 MeV and Pair production in the nuclear field starts at photon energy 1.02 MeV and the mass attenuation coefficients increases with increasing energy (Isikli and Oto,2017; Zenobio et al., 2015). Fig. 2 and 3, it is seen that these three events dominate and occur in three different energy ranges.

Table1. some chemical compouds of target tocalculate half value thickness experimentally

Material	Magnesiu oxide	Aluminum oxide	Silicon oxide
Symbol	MgO	Al_2O_3	SiO_2
Atomic Weight	40.305 g/mol	101.96 g/mol	60.08 g/mol
Color	white, crystalline \ Solid	white, crystalline \ Solid	white, crystalline Solid
Melting P (°C)	2,852	2,072	1,610
Theoretic Density (g/cc)	3.6	3.97	2.65

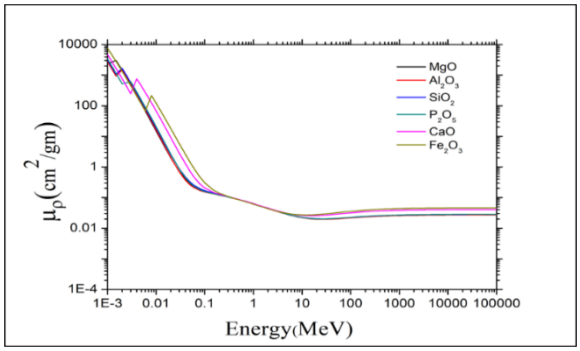

Figure 2: Mass attenuation coefficients.

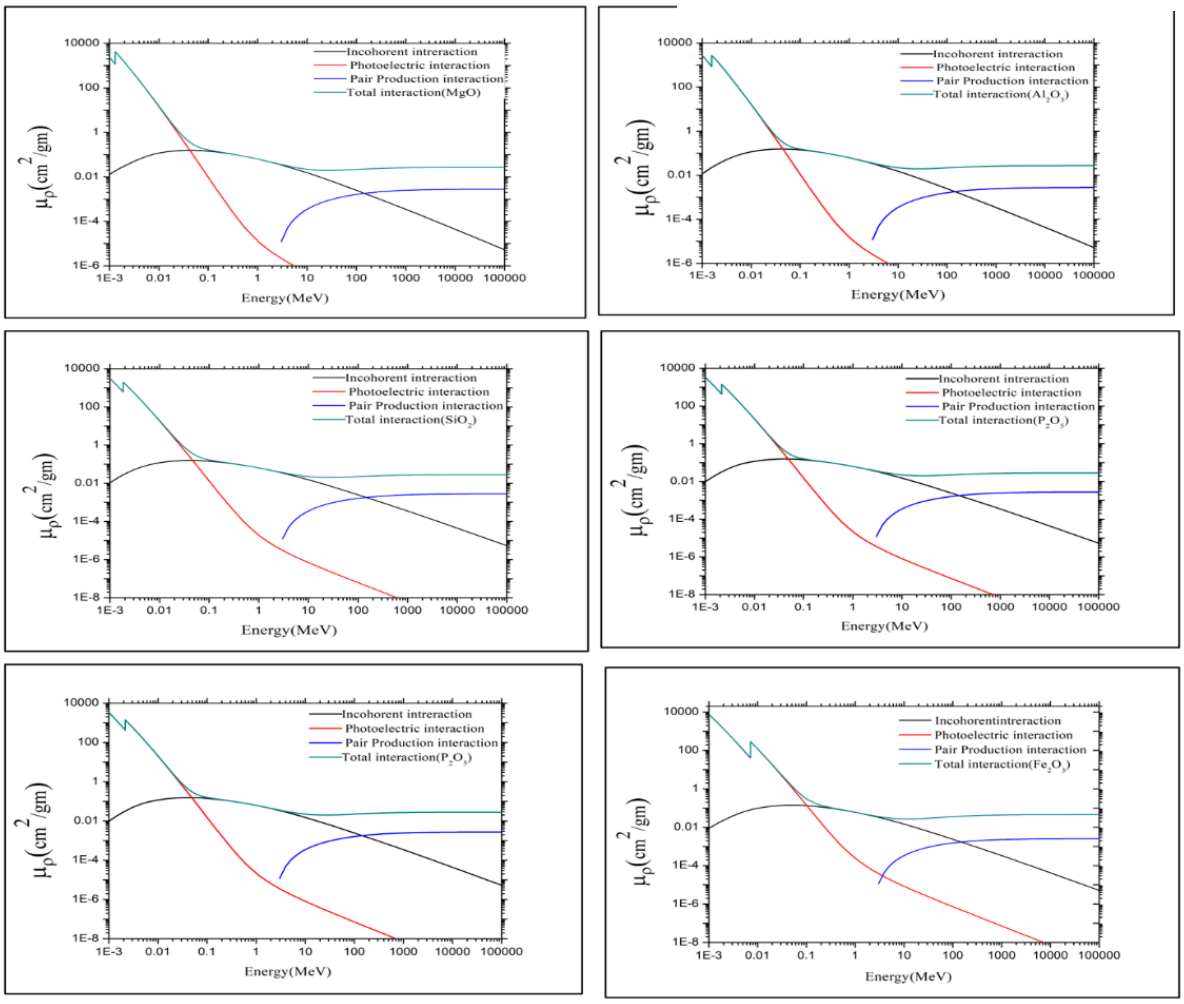

Figure 3: Mass attenuations coefficient (μ_ρ) Energy for compounds in the: total interaction, photoelectric effect, Compton Mass attenuations coefficient (μ_ρ)versus Energy for compounds in the total interaction.

The interactions of photon parameters vary with energy, depending on the types of compound. Fig .2 and 3 shows the μ_ρ versus photon intretactions for MgO, Al_2O_3, SiO_2, P_2O_5, CaO and Fe_2O_3 in the all interaction. As expected, the linear attenuation coefficients of all samples studied decreased as photon energy increase.The overall interaction zone is split into three reigns: low, medium, and high energy.as can be observed. It is accepted (Abbad and Mohammad,2011; Zaim and Bayhatun ,2018.). The photoelectric absorption phenomena is strong in the low energy area, with maximum values and rapidly decreasing with increasing energy. In this energy range, the photoelectric effect's cross section is directly proportional to Z^3.

The Compton scattering phenomenon dominates in the intermediate energy area. the μ_ρ values proportional to the Compton scattering cross-section Z, so it can be seen all compounds have the same value μ_ρ. Because the N_A of each elements are close to each other it is agreed with (Singh at el.,2014). In high energy regions, pair formation becomes dominant process. Since the double formation cross section is proportional to Z^2, μ_ρ values were found to be constant after a certain energy value (Akkurt & El-Khayatt, 2012).

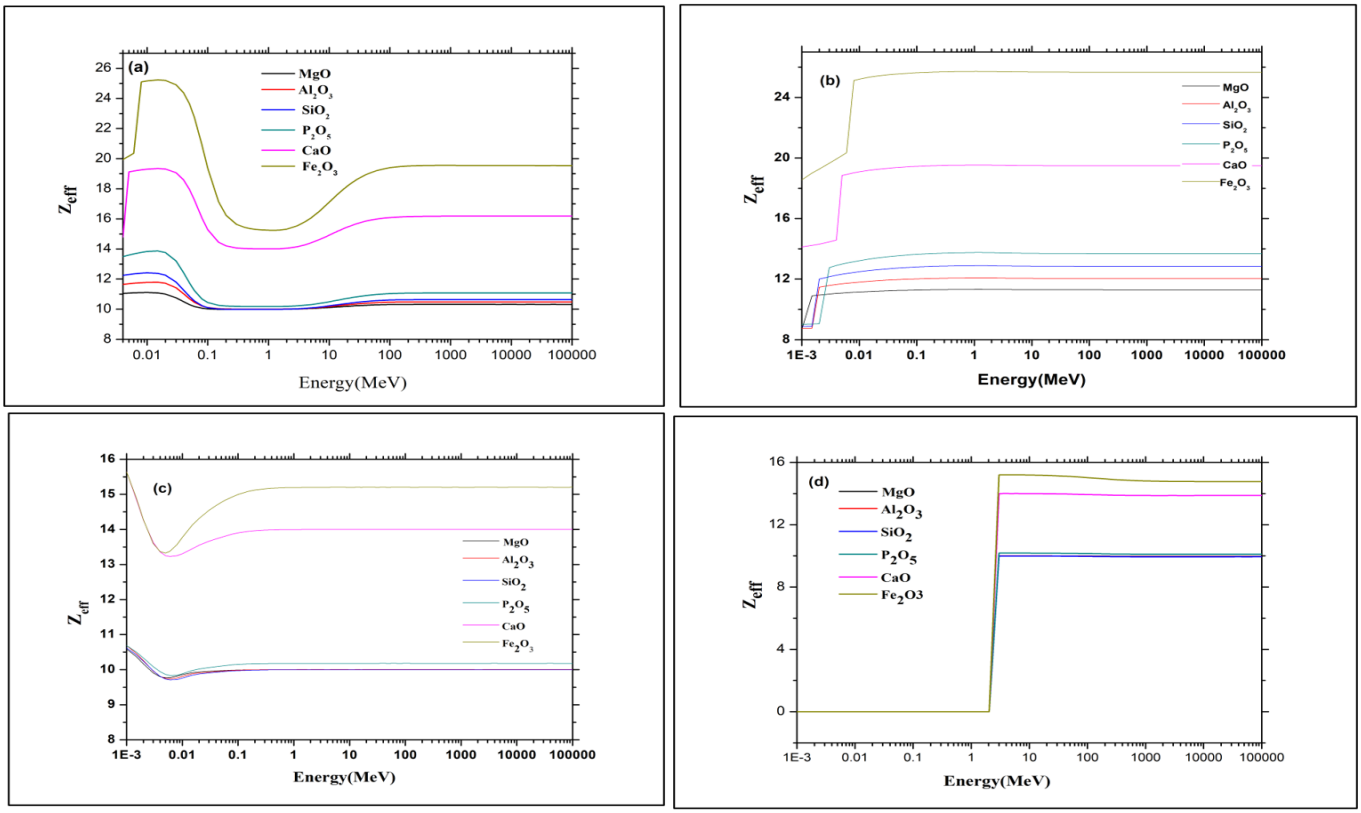

Figure 4: Z_{eff} versus Energy for compounds in the :(a) total interaction (b)photoelectric effect, (c) Compton effect and (d) pair production of compounds ((MgO, Al_2O_3, SiO_2, P_2O_5, CaO and Fe_2O_3)

The variation of Z_{eff} in compounds with incoming photon energy (MgO, Al_2O_3, SiO_2, P_2O_5, CaO and Fe_2O_3 as shown in Fig. (4). The Z_{eff} of a material is an essential word for characterizing the degree of attenuation caused by various partial photon interaction mechanisms. Figure 4 (a) shows the fluctuation of Z_{eff} with compound energy. The Z_{eff} values clearly changed with energy and compound. Fig. 4 (a). demonstrates how Z_{eff} values vary as photon energy increases from 1 keV to 100000 MeV. The compounds Fe_2O_3 and CaO have the highest Z_{eff}, whereas MgO has the lowest. This is mostly dependent on the elements Fe and Ca, which have very high atomic numbers (Z = 26 and 20). Furthermore, as energy increases, Z_{eff} drops before increasing. Because

photoelectric absorption occurs at low energies and is proportional to Z^4, it is agreed with. (Manohara and Hanagodimath, 2007; Prasad et al.,1998).

It has been observed that Z_{eff} for compounds started rises an incident photon energy of up to 0.001 MeV and therefore rapidly decline up to 0.01MeV. In total interaction after (100) MeV for compound MgO, Al_2O_3 and SiO_2 it was constant however for compounds P_2O_5, CaO and Fe_2O_3 at (300) MeV it constant. Because the Z_{eff} of a complex compound is the number of electrons around the core metal.

(Z_{eff}) versus energy for compounds in the photoelectric interaction, compton and piar production separately can be seen in Fig. (4.b-4.d). It was determined that the Z_{eff} of the compounds in the photoelectric effect are larger than compoton scattering and pair production (Manjunathaguru and Umesh., 2006; Kumar, 2016).

The "effective electron number or electron density," is defined, on the other hand, as the number of electrons per unit mass of the absorber (Shivalinge et al., 2005).

Figure 5(a-d) shows the predicted Photon energy influences the electron density. It grew dramatically at first energy as well as its lowest values are around 0.1 MeV, close to concrete's effective atomic number.

Fig 5. Electron density (N_{el}) versus Energy for in the (b: photoelectric interaction:c incohorent interaction, and d: pair production interaction). Fig (5.b) electron density (N_{el}) become constant near 0.01 MeV for all compounds. however, in Fig (5.c) Electron density (N_{el}) for compounds have minimum value at 0.01MeV become constant after 0.1 MeV.

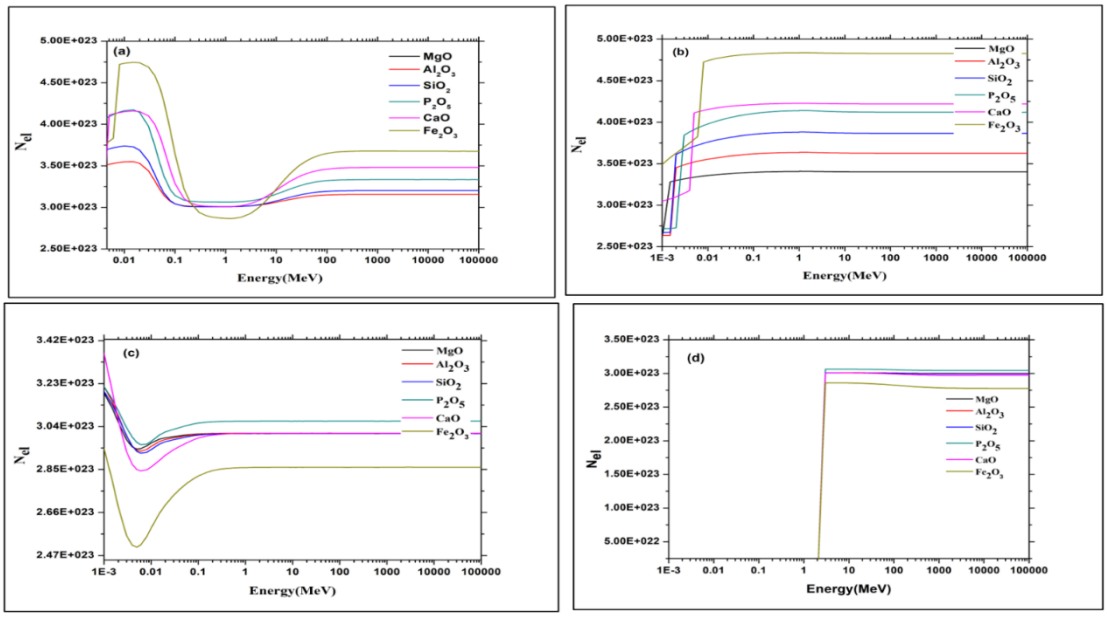

Figure 5: Nel versus Energy for compounds in the:(a) total interaction (b)photoelectric effect, (c) Compton effect and (d) pair production of compounds ((MgO, Al2O3, SiO2, P2O5, CaO and Fe2O3).

CONCLUSIONS

In this study, mass Attenuation coefficients of some chemical substances in bone (MgO, Al_2O_3, SiO_2, P_2O_5, CaO, and Fe_2O_3. were obtained using the NistXCom program and plotted against energy. We calculated according to the total mass attenuation coefficients of the compounds. At the same time, the mass attenuation coefficients and half value thickness of some compounds were measured experimentally. The energy range analyzed was displayed versus electron density and effective atomic number. Three regions where photoelectric, Compton and pair formation events were dominant. Photoelectric interaction was observed to be effective in the low-energy region. In this region, the active atomic number (Z_{eff}) of the substance had maximum values. That is, the atomic number in the compound is the highest. Compound was not affected much. Since the scattering in the intermediate energy range where

Compton scattering is prevalent, σ is proportional to Z, in this energy area, the Z_{eff} values were found to be lower than the other regions, since the contribution from the Compton scattering to the mass reduction coefficient is the least compared to other photon interaction types. A weak increase in Z_{eff} values was observed in the area of high energy where the pair formation event is dominant. The reason for this increase is that the probability of double formation event changes proportionally with Z^2. The comments made for Z_{eff} values are also valid for Nel values. Therefore, the active atoms of the chemical elements and compounds interacting with the photon vary in the study. The most changes were seen in the Compton area.

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