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Study of the mass attenuation coefficient and effective atomic number for partial interaction processes of polymers ($C_6H_{11}ON$), ($C_{11}H_{21}ON$), (C_6H_{12}) and (C_2H_4)

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ABSTRACT

The mass attenuation coefficient (μ/ρ) of many polymers, such asPolyamide-6 ($C_6H_{11}ON$), Nylon 1,1($C_{11}H_{21}ON$), Polymethyl pentane(C_6H_{12}), and High density Polyethylene(C_2H_4), was determined in the available energy range (5.89-2.5*10^3) KeV using the XCOM code and the Phy-X/PSD program. The values of μ/ρ are higher when the photo-electric effect is dominant in 5.89 KeV of photon energy, but they are almost constant above 0.138 KeV of photon energy when the Compton scattering is dominating. These results showed a good agreement. Partial processes of interaction can explain variations in (μ/ρ) values. The effective atomic number (Zeff) was calculated with the XCOM code for several polymers. Z_{eff} is the highest value in the photo-electric effect zone and is constant or almost constant in the Compton scattering region.

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دراسة معامل التوهين الكتلي والعدد الذري الفعال لعمليات التفاعل الجزئي ل ($C_6H_{11}ON$)و ($C_{11}H_{21}ON$), (C_6H_{12}) ,(C_2H_4)

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الكلمات المفتاحية:
اشعة كاما
معامل التوهين الكتلي
العدد الذري الفعال

الــخُــلاصــة

تم تحديد معامل التوهين الكتلي (μ/ρ) للبوليمرات المختلفة بما في ذلك Polyamide-6 ($C_6H_{11}ON$) Nylon 1,1, ($C_{11}H_{21}ON$) و Polymethyl pentane , (C_6H_{12}) و High density Polyethylene (C_2H_4) في منطقة الطاقة (5.89-2.51*10^3)كيلو الكترون فولت

بأستخدام كود X-COM و Phy-X/PSD . تكون قيم (μ/ρ) كبيره عندما يكون التأثير الكهروضوئي هو المهيمن عند طاقة الفوتون 5.89 كيلو الكترون فولت ، ولكن عندما يكون تشتت كومبتون هو المهيمن، تكون هذه القيم ثابتة تقريبًا عندما تكون طاقة الفوتون اعلى من 0.138 كيلو الكترون فولت واظهرت هذه النتائج توافقا جيدا . توفر عمليات تفاعل الفوتون شرحًا للتغيرات في قيم (μ/ρ). تم حساب العدد الذري الفعال (Z_{eff}) أيضًا باستخدام برنامج XCOM وقد وجد ان العدد الذري الفعال له قيمة اعلى في منطقة التأثير الكهروضوئي ويصبح ثابتًا أو شبه ثابت في منطقة تشتت كومبتون لنفس قيم الطاقة المذكوره.

1. INTRODUCTION

Gamma radiation has lots of applications in science and technology. These include the fields of industry, medicine, agriculture, petroleum production, and energy[1]. As a result of collisions of gamma-rays with matter, this can cause ionization indirectly. Because gamma rays are electromagnetic waves with no charge, [2]. Gamma rays interact with matter using three mechanisms: pair creation, Compton scattering, and the photoelectric effect, throughout the whole energy spectrum [3].

As gamma ray traveling in a narrow beam, it may lose energy due to any one of these three interactions, such as photoelectric effect ,Compton scattering pair production; as they can be absorbed or deflected in different directions[4]. An element's atomic number and density are related to its gamma and X-ray scattering and absorption. Effective atomic number is also connected to composite materials [5][6] Since the composite material of the elements affects the partial interaction cross section over the complete energy range. The atomic number of a composite substance cannot be represented by the atomic number of an individual element. The effective atomic number, a unique metric for composite materials, varies with energy. [6] Composites are materials composed of two or more constituent elements that possess markedly diverse physical or chemical characteristics, remaining separate and distinct at a macroscopic level inside the composite. The various elements come together to provide the composite with characteristics that set it against its component parts. Composite materials encompass, among others, metals, soils, biological substances, glasses, polymers, and solutions.As a result, photon interaction with composite materials differs from photon interaction with single elements in general. The popular "mixture rule" is based on the presumption that, because the materials are made up of different elements, each composite element's contribution to the overall photon interaction is additive [7]. Polymers are essential for shielding against gamma radiation[8]. Polymers have several beneficial qualities, including softness, insulators, elasticity. Polymer materials are C-, H-, O-based and known as low-Z materials , that are not inflammable, having low weight, and are less expensive, more stable on high temperature, and has broad applicability [9]. They may be subjected to ionizing radiation for an extended period of time because they are also utilized in power plants[10]. This work employed the Phy-X/PSD software and WinXcom code to compute the gamma-ray attenuation properties of selected polymers, including mass attenuation coefficient(MAC) and (Z_{eff}).

2. COMPUTATIONAL WORK

Utilizing X-COM code and the Phy-X/PSD program, mass attenuation coefficient (MAC) of some polymers was determined for a range of gamma radiation sources, including, ^{109}Cd, ^{133}Ba, ^{22}Na, ^{241}Am, ^{60}Co, ^{55}Fe, ^{137}Cs, and ^{131}I, within the energy region that ranges from ($5.89*10^{-3}$ to2.51) MeV. Use of the X-COM code to compute the (Z_{eff}) of certain polymers in the range of (5.89 to $2.51*10^3$) KeV.

2.1. Mass attenuation coefficient (μ_m)

MAC is representing the likelihood of interaction between gamma rays and the mass per unit area of a material, may be determined using the established Beer–Lambert formula.[11]:

$$I = I_0 e^{-\mu t} \quad (1)$$

$$\boldsymbol{\mu_m} = \left(\frac{\mu}{\rho}\right) = \frac{\ln(I_0/I)}{\rho t} \quad (2)$$

where μ (cm^{-1}) and μ_m (cm^2/g) are linear and mass attenuation coefficients, t (cm) is the thickness, and ρ (g/cm^3) is the material density. I_0 and I represent the un-attenuated and attenuated photon intensities.

2.2. Effective atomic number (Z_{eff})

This is defined as the ratio of the total atomic cross- section to the total electronic cross -section [12] :

$$Z_{eff}=\frac{\sigma_a}{\sigma_e} \quad (3)$$

From the values of (MAC) , the (σ_a) can be calculated using the following formula:

$$\sigma_a=\frac{\mu_m}{N_a \sum_i \frac{w_i}{A_i}} \quad (4).$$

Likewise, one can use the following formula to find (σ_e) [11]:

$$\sigma_e=\frac{1}{N_A}\left(\sum_i \frac{f_i A_i}{Z_i}(\mu_m)_i\right) \quad (5)$$

where N_A, Z_i, f_i , $(\mu_m)_i$, w_i and A_i are the Avogadro's number, atomic number, mole fraction, mass attenuation coefficient, weight fraction and atomic weight of the i^{th} constituent element, respectively.

3.1 Calculation of Mass attenuation coefficient

Phy-X/PSD was utilized to calculate the (μ_m) for certain polymers, and the outcomes had been compared with X-COM for the accessible energies. The results showed good agreement and Figures were plotted using a Matlab program. The values of μ_m decrease as photon energy raises. Due to the dominance of the photo-electric effect, the values of μ_m are large in the low energy zone and rapidly decrease with increasing energy. When Compton scattering predominates, the mass attenuation coefficient values gradually decrease as energy increases [13][14] as shown in figure 1. The mass attenuation coefficients depend on photon energy and the chemical composition of the materials, as seen in the figure below. The dominance of partial photon interactions with polymers (photoelectric absorption, coherent scattering, incoherent scattering, and pair production in nuclear and electron fields) elucidates the variation of (μ_m) with photon energy. The interaction mechanisms (photoelectric effect, Rayleigh scattering, and Compton scattering) of ionizing electromagnetic radiation (gamma rays) with a composite material are defined by the effective atomic number. [5]. The kind of radiation, material thickness, effective atomic number of the compound, radiation intensity, and energy of the incident photons all influence the extent of radiation attenuation by a material. In the next subsections, the entire variance in (μ/ρ) of polymers for processes involving partial interactions with photon energy is explained.

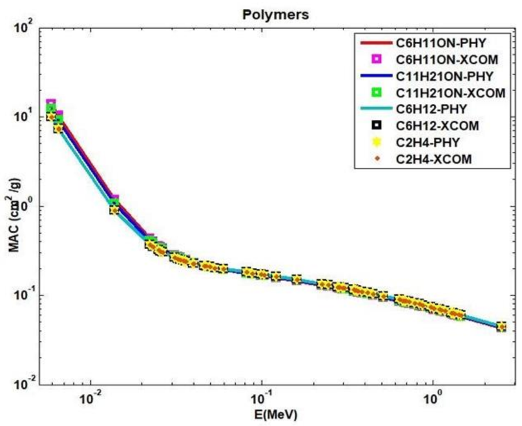


Figure. 1: Variance of mass attenuation coefficient with photon energy

3.2: Calculating the Mass attenuation coefficient in partial interaction processes

3.2.1 Photoelectric absorption process

All polymers exhibit a quick drop in $\mu_{m(\ photo)}$ at low energy, as illustrated in Figure.2. Because photo-electric effect is dominant, the value of $\mu_{m(photo)}$ is very large at 5.89 KeV and rapidly drops at low energy. Because the photo-electric absorption cross section is decrease with increasing the photon energy ($1/E^{3.5}$) and increase with increasing the atomic number (Z^4 at low energy and Z^5 at high energy), some polymers exhibit a rapid drop in $\mu_{m\ (photo)}$ at low photon energies [15][16][12]

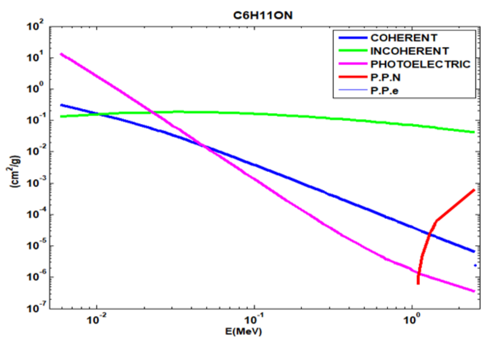
3.2.2 Compton scattering process (Incoherent scattering)

Figure. 2 shows that $\mu_{m\ incoherent}$ above 0.138 Kev become nearly constant because Compton scattering is the dominant process, values of mass attenuation coefficient Almost similar for all materials and this is due to the fact that the cross section of the Compton Scattering process is inversely proportional to the incident photons energy (1/E) and it varies linearly with the atomic number (Z)[12].

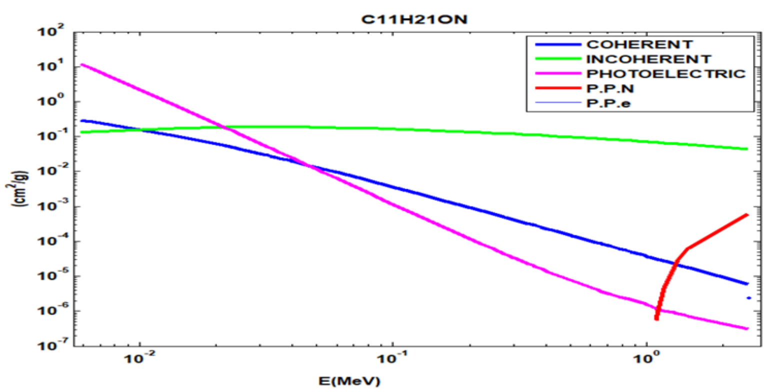
Figure.2 shows that for all selected polymers, $\mu_{m\ coherent}$ decreases as the energy of photon increases.

3.2.3 Pair production process

Figure.2 displays the values of μ_m in pair production process in the electron field μ_m (epp.) and nuclear field μ_m (npp.). These values start at threshold energies of 1.022 MeV and 2.044 MeV, respectively, and then raises with photon energy increases. Figure.2 offers additional support, showing that even at 1.022 MeV, a high incident photon energy is required for the pair production process to surpass Compton scattering and dominate photon interaction processes[1].



(a)



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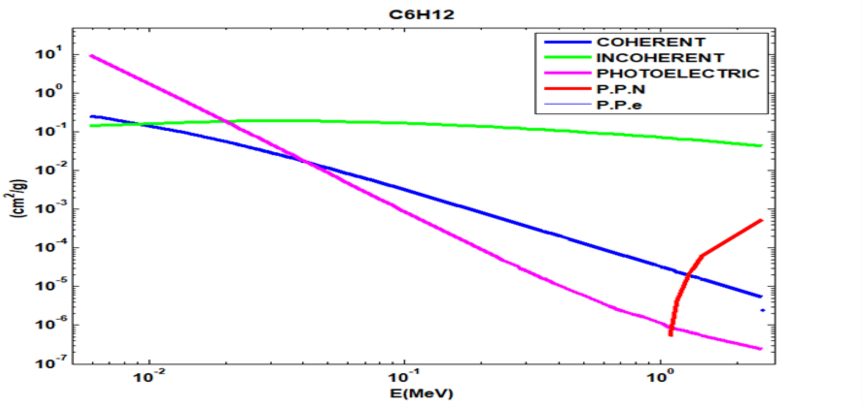

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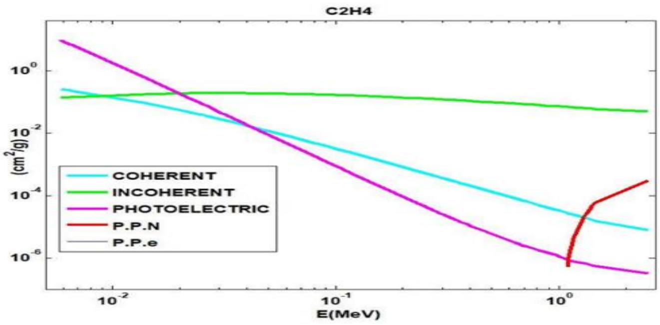

(d)

Figure. 2: Variance of the mass attenuation coefficients for photoelectric, Compton and pair production for polymers

3-3 Effective atomic number (Z_{eff})

The effective atomic number of selected polymers was determined using the Phy-X/PSD code , and a matlab program was used to draw the Figures. The Z_{eff} decreases as the incident photon energy rises, Z_{eff} values are high in the low energy zone because photo-electric absorption predominates there. Due to predominant Compton scattering, Z_{eff} values reduce with rises energy and stabilize or remain virtually constant, exhibiting minimal variation over the analyzed energy range.[17] Figure 3 demonstrates the variation of the effective atomic number of selected polymers with photon energy. The polymers selected have effective atomic number values that lie between those of their constituent elements ($1< Z_{eff} <7$). The ($C_6H_{11}ON$) has the highest Z_{eff} ,which may be due to that it contains larger amount of Nitrogen (w_i=0.1238) than other polymers[18][14].C_2H_4 and C_6H_{12} have the same effective atomic number because this polymers have the same weight fraction of elements

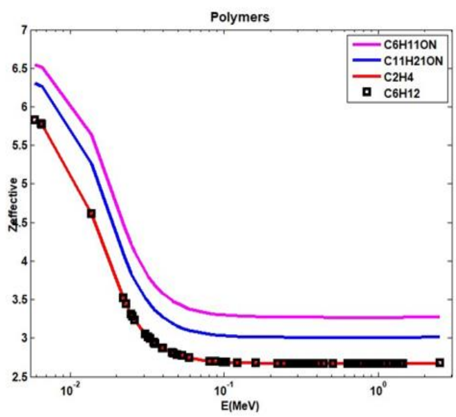

Figure. 3 :Variance of the effective atomic number with photon energy for all polymers

4. Conclusions

This study presents the γ-ray mass attenuation coefficients and effective atomic numbers for several polymers., including ($C_6H_{11}ON$), ($C_{11}H_{21}ON$), (C_6H_{12}), and (C_2H_4), in the energy region (5.89- 2.51*10^3) KeV. There was a good agreement found between the X-COM and Phy-X/PSD results for μ_m. Our findings indicate that MAC and Z_{eff} of polymers mostly vary within the photoelectric absorption and Compton scattering regions. and are depending on photon energy and composition element. Low energy, high MAC and Z_{eff} values were found in the photo-electric absorption zone.

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