The evaluation of mass attenuation of charcoal

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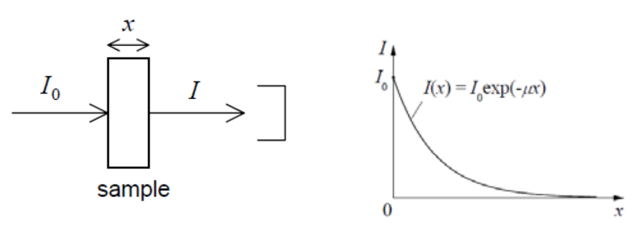
Abstract- In this paper, the mass attenuation coefficient of the charcoal has been calculated by using a theoretical method depends on differential cross section, for following interactions (photoelectric which taken from Scofield 1973, Rayleigh which taken from Hubbell and Overbo 1979, Compton scattering which taken from Hubbell et al. 1975).The energy band ranged from (1keV – 1 MeV). The graph mass attenuation coefficient versus the energy shows that the maximum mass attenuation coefficients appear at the energy value (1 keV).

Keys words- mass attenuation, photoelectric effect, Compton, Rayleigh, Attenuation

1- Introduction

The attenuation coefficient is an important parameter which is widely used in industry agriculture, science, and technology, etc….the properties characterizing the penetration and diffusion of X-rays in composite materials such as charcoal are very important [1]. Charcoal is characterized as available and cheap price and also accessibility, and is composed mainly of carbon with a small percentage of vegetable cellulose.The attenuation coefficient is a basic quantity in calculation of penetration of materials by radiations or energetic beams. The attenuation coefficients, also called the narrow beam attenuation coefficient, is a quantity, which describes the extent to which the intensity of a beam is reduced as it passes through the material. The X-ray intensity transmitted through a dense material is given by:[1]

$$I = I_o \exp(-\mu x)......(1)$$



(a) (b)

Fig(1) :a)decreasing the radiation intensity from I to I_0 as penetrating the material b) as thickness of material increase the intensity decreased.

Where I is the transmitted X-ray intensity, I0 is the incident X-ray intensity, μ is the linear attenuation coefficient (in cm-1) and x is the thickness of the material (in cm). This equation shows that the X-ray intensity depends on:
-The density of the material (the linear attenuation coefficient μ increases with density).
-The thickness of the material.

When the geometry of the sample is known, the X-ray *images can be used to determine densities quantitatively.* The Energy Loss by electrons Contributing Processes are as the following

1. Atomic photoelectric effect
2. Rayleigh scattering
3. Compton scattering of an electron
4. Pair production (nuclear field)
5. Pair production (electron field)
6. Photonuclear interaction

The range of energy (1keV – 1 MeV) that employed in the calculations, this research work responsible to three kinds of interaction (Rayleigh, photoelectric and Compton) [2].

2-Photoelectric Interactions

The photoelectric effect or photo-ionization, is a process in which a X-ray photon impinging on an atom transfers its entire energy to an inner shell (e.g. K shell) electron of the atom. The electron (named photoelectron) is ejected/excited/ionized from the atom. The kinetic energy of the ejected photoelectron is equal to the incident x-ray photon energy minus the binding figure(1)

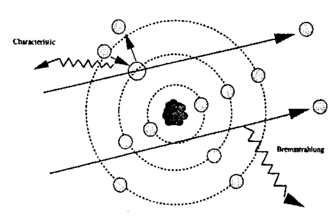


Fig.(2):depicts a simplified mechanism of x-ray production.

energy of the electron. The vacancy resulting from the ejection is filled by an electron from an outer orbit (e.g. L shell) with lower binding energy, leaving a vacancy in this outer orbit, which in turn is filled by another electron from an orbit even further away (e.g. M shell) from the nucleus.

The surplus energy liberated when an electron drops from its outer shell to a shell closer to the nucleus results in emission of characteristic radiation (e.g. K_α line). The energy of the characteristic radiation is equal to the difference in binding energies between shells. Figure 1 (a) depicts a simplified atomic structure with ejected electron under x-ray excitation. The corresponding energy level diagram of an atom is shown in Figure 1 (b), illustrated the excitation of K, L, M and N shells and the formation of $K_\alpha, L_\beta, M_\alpha$ and N_α emissions.[2]

3-Coherent scattering,

The Rayleigh scattering, is an elastic process where a photon impinging on an atom is scattered without loosing its energy. The energy of X-ray photon is firstly completely absorbed and then re-emitted by electrons of an atom. The scattered photon has the same phase as the incident photon ($\lambda_{out} = \lambda_{in}$), however the direction of re-emission is totally arbitrary. The probability of this process increases with decreasing energy of the photons and increasing atomic number of the scattering atom. [3]

4-Compton scattering,

The incoherent scattering, can be considered as a collision between X-ray photon and one of the outer shell electrons of an atom. The outer shell electron is bound with very little energy to the atom and is easy to be ionized. The kinetic energy to help electron's ejection from the atom is transferred from the incident photon, leaving the scattered X-ray with less photon energy ($E_{out} < E_{in}$) and longer wavelength ($\lambda_{out} > \lambda_{in}$). The probability of this process falls gradually with energy of the photons and independent of atomic number of material [4] .Because energy and momentum are both conserved in this collision, the energy and direction of the scattered x-ray photon depend on the energy transferred to the electron. When the incident x-ray energy is high, the relative amount of energy lost to the electron is small, and the scattering angle is small relative to the initial direction. When the incident X-ray energy is small, the scattering is more isotropic in all directions. In X-ray energies on the order of 1 MeV, the scattering is mostly in the forward direction. And in x-ray energies of near 0.1 MeV, the scattering is more isotropic.[4]

$\hbar\omega \prec 100keV$ photoelectric absorption dominates

$100keV \prec \hbar\omega \prec 1MeV$ Thomson and Compton scattering

$\hbar\omega \geq 1MeV\left(= 2m_e c^2\right)$ pair production dominates

5-Theoretical calculation

The linear attenuation coefficient reflects the removal of X-ray photons from a beam by interaction with electrons of the material probed. The higher the electron density, the more interaction of X-ray photons with the sample material occurs. These interactions can be absorption of the photons (removal from the beam) or scattering (change of direction with reduction in energy). Therefore appropriate to scale the linear attenuation coefficient with the sample density. The linear attenuation coefficient can be rewritten as: [5]

$$\mu = \left(\frac{\mu}{\rho}\right)\rho......(2)$$

Where μ/ρ is the mass attenuation coefficient (cm2/g) and ρ is the density (g/cm3). The mass attenuation coefficient is approximately constant for different materials in a specified energy range, and therefore the linear attenuation coefficient is strongly determined by the density. The linear attenuation coefficient is also strongly energy dependent. In general, lower energetic X-ray photons have a higher interaction probability. Since an X-ray device produces photons in a wide energy range, the transmission should actually be considered for the whole energy range. For composite materials, the intensity is given by adding the individual contributions of each chemical element:

$$I = I_o \exp\left(-\sum \mu_1 x_1\right).....(3)$$

which can be rewritten as:

$$I = I_o \exp\left(-\sum\left(\frac{\mu}{\rho}\right)\right)......(4)$$

When the composite material is a homogeneous mixture of several elements, the sample is characterized by a single thickness. The linear attenuation coefficient can then be written as:

$$\mu_{mix} = \sum\left(\frac{\mu}{\rho}\right)\rho_1......(5)$$

If the thickness of sample is known, it allows us to evaluate the density distribution of sample under study. The μ/ρ provided in NIST database rely heavily on theoretical values of the total attenuation cross section per atom, σ_{tot}, which is related to μ/ρ according to

$$\mu/\rho = \sigma_{tot}/uA..........(6)$$

Where u is the atomic mass unit (u = 1.66x10^{-24} g) and A is the atomic mass of the target element. σ_{tot} is the total cross section for an interaction by the photon, frequently given in units of b/atom (barns/atom), where b = 10^{-24} cm^2. The attenuation coefficient, photon interaction cross section and related quantities are functions of the photon energy. Explicit indication of this functional dependence has been omitted to improve readability. The total cross section can be written as the sum over contributions from the principal photon interactions: [6]

$$\mu/\rho = \left(\sigma_{pe} + \sigma_{coh} + \sigma_{comp}\right)/uA \text{..........}(7)$$

Where σ_{pe} is the photoelectric absorption cross section which taken from Scofield 1973[7], σ_{coh} which taken from Hubbell and Overbo 1979[8] and σ_{comp} which taken from Hubbell et all[9].

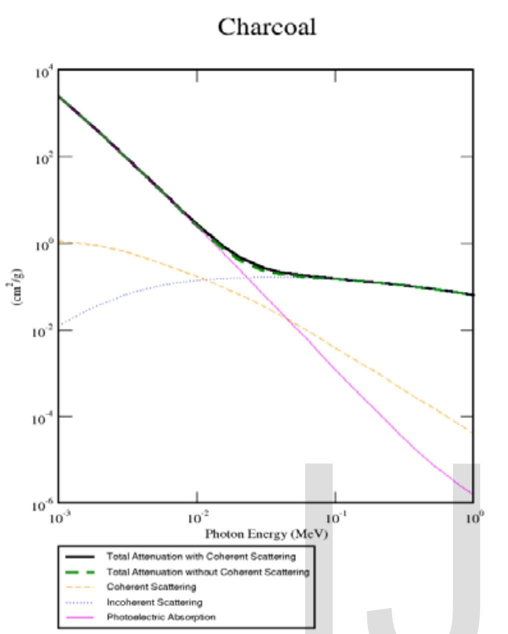


Fig.2: Shows the behavior of interaction between the rang (1k e.V – 1 MeV) with the Charcoal.

6-Results and Discussion

The calculated mass attenuation coefficients of interactions (Rayleigh, photoelectric and Compton) for energies (1k eV – 1 MeV) has been plotted in figure.2 which show $\frac{\mu}{\rho}$ have maximum value about 1.8 k eV. The figure 2 shows total mass attenuation coefficient have a maximum value in the range about 1keV then the values will decrease until it have a minimum values in the range of high energies .In the table (1) we can note all of the interaction that occurring between the Charcoal with the energies (1 keV – 1 MeV) and which represents the values of attenuation such as Scattering (Coherent and Incoherent),Photoelectric Absorption, Pair Production(In Nuclear Field and In Electron Field) and Total Attenuation (with coherent and without coherent).The action of Pair Production(In Nuclear Field and In Electron Field) did not show as appearance in both of table(1) and fig.2 because of the range of energies less than the level of this action .

7- The Conclusion

1-We can conclude the Charcoal a good shield to the spectrum's band that carrying the (1keV) .

2-After the value (1 MeV) it is possible appearance values to the Pair Production(In Nuclear Field and In Electron Field) but in this case the values of Total Attenuation will decreasing because of the probability of occurring the interaction between the photons and the electrons will decreasing with the increasing of photon's energy.

3-As clear in Fig. 2 that the total mass attenuation coefficient are coincidence in values this refers to that fact in coherent scattering never lost energy .

4-In the energy rang (0.001-0.002MeV) as shown in table 1, the mass attenuation coefficients for several interactions are equivalent ,exactly :Incoherent with photoelectric and incoherent with coherent as well as the photoelectric with coherent.

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Table (1): the types of interaction between the rang (1k e.V – 1 MeV) with the Charcoal .

Edge	(required) Photon Energy	Scattering		Photoelectric Absorption	Pair Production		Total Attenuation	
		Coherent	Incoherent		In Nuclear Field	In Electron Field	With Coherent Scattering	Without Coherent Scattering
	MeV	cm2/g	cm2/g	cm2/g	cm2/g	cm2/g	cm2/g	cm2/g
	1.000E-03	1.112E+00	1.269E-02	2.417E+03	0.000E+00	0.000E+00	2.418E+03	2.417E+03
	1.500E-03	9.932E-01	2.526E-02	7.744E+02	0.000E+00	0.000E+00	7.754E+02	7.745E+02
	2.000E-03	8.671E-01	3.897E-02	3.366E+02	0.000E+00	0.000E+00	3.375E+02	3.367E+02
	3.000E-03	6.456E-01	6.482E-02	1.010E+02	0.000E+00	0.000E+00	1.017E+02	1.011E+02
	4.000E-03	4.878E-01	8.557E-02	4.221E+01	0.000E+00	0.000E+00	4.278E+01	4.229E+01
	5.000E-03	3.815E-01	1.009E-01	2.124E+01	0.000E+00	0.000E+00	2.172E+01	2.134E+01
	6.000E-03	3.092E-01	1.121E-01	1.205E+01	0.000E+00	0.000E+00	1.247E+01	1.216E+01
	8.000E-03	2.208E-01	1.273E-01	4.872E+00	0.000E+00	0.000E+00	5.220E+00	4.999E+00
	1.000E-02	1.697E-01	1.374E-01	2.394E+00	0.000E+00	0.000E+00	2.702E+00	2.532E+00
	1.500E-02	1.018E-01	1.531E-01	6.486E-01	0.000E+00	0.000E+00	9.035E-01	8.017E-01
	2.000E-02	6.742E-02	1.615E-01	2.539E-01	0.000E+00	0.000E+00	4.828E-01	4.154E-01
	3.000E-02	3.512E-02	1.674E-01	6.691E-02	0.000E+00	0.000E+00	2.694E-01	2.343E-01
	4.000E-02	2.137E-02	1.672E-01	2.580E-02	0.000E+00	0.000E+00	2.144E-01	1.930E-01
	5.000E-02	1.434E-02	1.649E-01	1.229E-02	0.000E+00	0.000E+00	1.915E-01	1.772E-01
	6.000E-02	1.026E-02	1.618E-01	6.699E-03	0.000E+00	0.000E+00	1.787E-01	1.685E-01
	8.000E-02	5.983E-03	1.550E-01	2.570E-03	0.000E+00	0.000E+00	1.635E-01	1.575E-01
	1.000E-01	3.900E-03	1.484E-01	1.224E-03	0.000E+00	0.000E+00	1.535E-01	1.496E-01
	1.500E-01	1.769E-03	1.343E-01	3.217E-04	0.000E+00	0.000E+00	1.364E-01	1.347E-01
	2.000E-01	1.002E-03	1.234E-01	1.266E-04	0.000E+00	0.000E+00	1.245E-01	1.235E-01
	3.000E-01	4.481E-04	1.075E-01	3.556E-05	0.000E+00	0.000E+00	1.080E-01	1.075E-01
	4.000E-01	2.525E-04	9.638E-02	1.518E-05	0.000E+00	0.000E+00	9.665E-02	9.640E-02
	5.000E-01	1.618E-04	8.806E-02	8.172E-06	0.000E+00	0.000E+00	8.823E-02	8.807E-02
	6.000E-01	1.124E-04	8.146E-02	5.084E-06	0.000E+00	0.000E+00	8.158E-02	8.147E-02
	8.000E-01	6.325E-05	7.157E-02	2.564E-06	0.000E+00	0.000E+00	7.164E-02	7.157E-02
	1.000E+00	4.049E-05	6.436E-02	1.594E-06	0.000E+00	0.000E+00	6.440E-02	6.436E-02

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