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Linear attenuation coefficient and mean free path in the energy range of 0.1MeV to 1.5MeV

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Abstract
The linear attenuation coefficient has an essential role in the estimation of absorbed dose use in the medical and radiation dosimetry. In this paper the linear attenuation coefficient and mean free path for the low density elements of Sulfur, Silicon, Sodium and Carbon in the energy range from 100keV to 1500keV were measured. The transmitted intensity of photons emitted by radioactive isotopes of ^{133}Ba, ^{22}Na, ^{137}Cs, ^{54}Mn and ^{60}Co measured using the NaI(Tl) scintillation detector and results obtained are in good agreement with the values reported in the literatures.

Keywords: NaI(Tl) Scintillation detector, linear attenuation coefficient, gamma radiation.

1. Introduction

The isotopes have importance due to the wide uses in the many fields like radiation dosimetry, medical physics, agriculture and industry. One of the fundamental parameter that is linear attenuation coefficient is important for characterizing the penetration and diffusion of gamma rays in the medium through which they passes. This mainly depends on the photon energy, the nature of the material and the density of medium [Bashter, I.I., 1997] [1]. The interaction of photon of gamma radiation takes place in different processes in the medium like photoelectric effect, incoherent scattering, coherent scattering and pair production and depends upon the energy of photon [Berger, M.J., Hubbell, J.H., 1987] [2].
Absorption coefficient is measure of the average fraction of incident photon energy translated into kinetic energy of charge particles via photo effect, scattering and pair production. Manohara, calculated the values of energy absorption for some biological molecules in the energy range1keV–20 [Manohara, S.R., Hanagodimath, S.M., 2008] [5]. The mass energy absorption coefficient theoretically calculated and tabulated form by Hubbell, J.H., Seltzer, S.M., [1995] [6]. Web side maintained by the National Institute of science and technology published and tabulated mass energy absorption coefficients over the large energy range. Ladhaf B.M. and Pravina P. Pawar determined the mass energy absorption coefficient and effective atomic energy absorption coefficient for Carbohydrates having elements Carbon, Hydrogen and Oxygen [Ladhaf, B. F. and Pawar, P. P. 2015] [8]. Hubbell calculated the mass energy absorption coefficient values theoretically for the C, H, N, O, Ar and Seven mixtures for the energies from 1keV to 20MeV [1982] [9] and one of the special review on the photon cross section [2006] [10]. The mass energy absorption coefficients are widely used in the radiation absorption dose. For the pure elements it is of importance like the applications in radiation shielding, protecting from high energy radiation and in the research field.

2. Methods and Theoretical basis

2.1 linear attenuation coefficients

Where, I_0 and I are the incident photon intensity and transmitted photon intensities through the material respectively, μ is the linear attenuation coefficient of the material for thickness t of sample is given by

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

Solving the Eq. (1), we get the following equation for the linear attenuation coefficient (cm^{-1}):

$$\mu = \frac{1}{t}\ln\left(\frac{Io}{I}\right) \quad (2)$$

The mass attenuation coefficients ($cm^2\ g^{-1}$) were obtained from Eq. (2) by dividing the density of the corresponding samples as follows,

$$\mu_m = \frac{1}{\rho t}\ln\left(\frac{Io}{I}\right) \quad (3)$$

Where, ρ (g/cm^3) density of the corresponding sample

2.2 Mean free path

Mean free path is the average distance at which a single particle travels through the medium of given sample before interacting it with material and is calculated by the following equation

$$X_m = \frac{1}{\mu} \quad (4)$$

3. Experimental set up and measurements

The experiments were carried out on interested elemental samples such as C, Na, Si and S was prepared in the form of pallets. Measure the incident and transmitted photon energies by using narrow beam good geometry gammaray spectrometer. The schematic arrangement of the experimental setup is shown in fig. 1.and the radio-isotopes which were used for the experiments are given in table 1. The detector used for the present work is NaI(Tl) scintillation detector having good resolution about 8.5% for the energy of 662keV, the signals from the detector were amplified and analyzed with 13-bit multichannel analyzer connected to the PC.

The samples are prepared in the form of pallet by weighted in a sensitive digital balance of having a good accuracy of measurements about 0.001 mg. The mean of this set of values was considered to be the mass of the sample. The KBr press machine was used to make the pallets of measured samples. The diameter of the pellets was measured by using the microscope and mean value of the mass per unit area was determined in each case. The sample thickness was selected in order to satisfy the following ideal condition as far as possible [Creagh, D. C., 1987] [11]. $2 \leq \ln (I_0 /I) \leq 4$

The elemental samples were irradiated by gamma rays of energies 122, 360, 511, 662, 840, 1170, 1275 and 1330ke Vin the air conditional lab by maintaining the temperature of the laboratory about 27 °C and measured the values of incident (unattenuated) photon intensity I_0 that is without samples and transmitted (attenuated) photon intensity I that is with samples and mean values are used for the calculation of linear attenuation coefficients (μ) for all selected elemental sample.

The nature of absorbing and scattering for the gamma-rays makes stringent demands on geometry, which includes a source of mono-energetic gamma radiation travelling in the small well collimated beam, an observer which is just sufficiently wide to cover the solid angle between source and adjusted distance of sample from the detector is as possible as minimum to minimize the scattering, all the elements used in the present study were of high purity (99.9 %), so the sample impurity is negligible for the measured data, the error due to the non-uniform thickness of samples is also negligible and also taken cared that physical condition remain constant.

4. Tables and Figures

Table 1: The information of radio-isotopes used for the experiments.

Isotopes	Half-ife	Activity(mCi)	predominant energy (keV)
^{133}Ba	10.5 (Y)	2324	356
^{22}Na	2.6 (Y)	1973	511
^{137}Cs	30 (Y)	2622	662
^{54}Mn	0.83 (Y)	3054	840
^{60}Co	5.27 (Y)	3622	1170
^{22}Na	2.6 (Y)	1973	1275
^{60}Co	5.27 (Y)	3622	1330

Table 2: Values of linear attenuation coefficient (cm^{-1}) for photon energies from 100keV to 1500keV

Sr.	Elements	Sulfur		Silicon		Sodium		Carbon	
No.	Energy	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.
1.	122	0.343	0.367	0.361	0.385	0.142	0.143	0.360	0.377
2.	356	0.209	0.212	0.233	0.237	0.094	0.094	0.263	0.264
3.	511	0.178	0.181	0.202	0.203	0.080	0.081	0.224	0.227
4.	662	0.160	0.162	0.181	0.181	0.072	0.072	0.201	0.204
5.	840	0.143	0.144	0.162	0.160	0.064	0.065	0.179	0.182
6.	1170	0.121	0.123	0.136	0.138	0.056	0.055	0.152	0.155
7.	1275	0.116	0.116	0.128	0.130	0.052	0.052	0.146	0.147
8.	1330	0.114	0.113	0.124	0.127	0.051	0.051	0.141	0.143

Table 3: Values of Mean free path (cm) for photon energies from 100keV to 1500keV

Sr.	Elements	Sulfur		Silicon		Sodium		Carbon	
No.	Energy	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.
1.	122	2.914	2.725	2.774	2.600	7.0202	7.0059	2.776	2.650
2.	356	4.774	4.710	4.294	4.215	10.672	10.609	3.798	3.789
3.	511	5.630	5.527	4.941	4.931	12.438	12.360	4.464	4.400
4.	662	6.258	6.185	5.533	5.513	13.898	13.807	4.963	4.911
5.	840	6.971	6.934	6.241	6.176	15.580	15.450	5.580	5.494
6.	1170	8.258	8.152	7.352	7.257	17.973	18.146	6.580	5.450
7.	1275	8.658	8.616	7.807	7.67	19.286	19.200	6.852	6.816
8.	1330	8.768	8.848	8.086	7.878	19.767	19.707	7.068	7.004

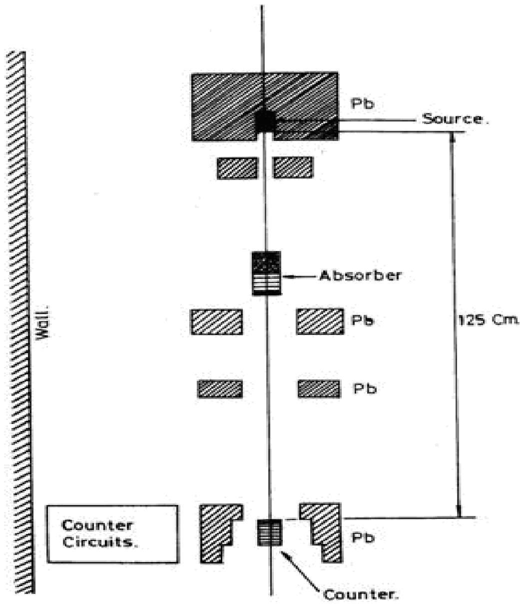

Fig 1: The schematic view of Scintillation counter

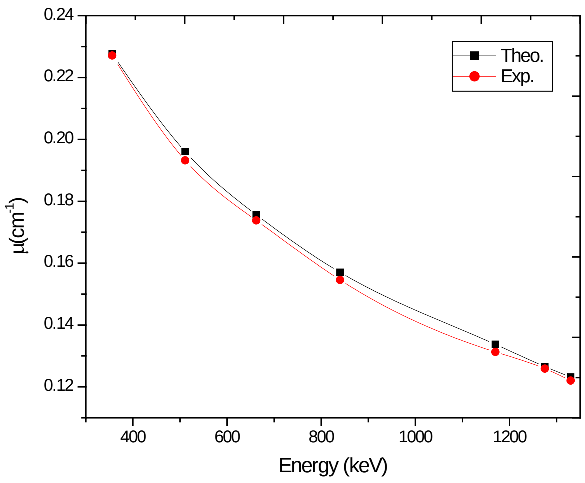

Fig 2: Variation of linear attenuation coefficient versus incident photon energy for Carbon

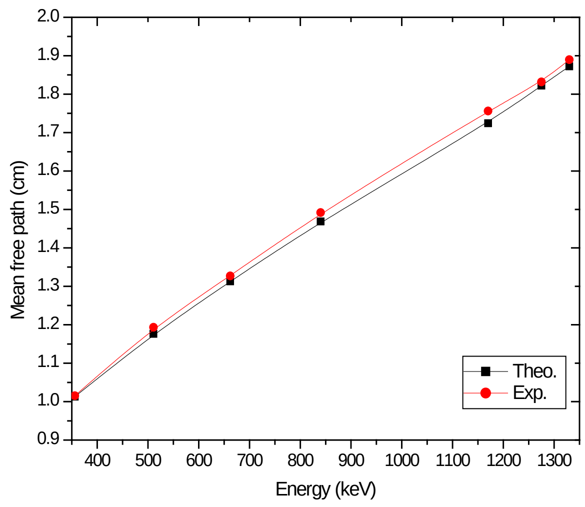

Fig 3: Variation of mean free path versus incident photon energy for Carbon

5. Results and Discussion

The linear attenuation coefficient is depends upon the density and energy of photon. Mostly at low photon energy the photoelectric effect predominant so the incident photon is absorbed by the electron which is related with the binding energy of electron and some photons are get scattered by losing its energy in Compton as well as Rayleigh scattering process. It is clearly seen that the linear attenuation coefficient values decreases as increases in the energy of photon given in table 2 and plotted against energy of incident photons in fig.3. The mean free path of photon increases with increases in energy of photon given in table 4 and plotted in fig3.

6. Conclusions

It has been observed that the linear attenuation coefficient is depending upon the interaction process of gamma radiation within the material which is related to the energy of photon and atomic number of elements. In the photon interaction of matter the values of linear attenuation coefficient (μ) decrease with increasing photons energy and depend upon the density of material but the mean free path increases with increases in the energy of photons and decreases with increasing the atomic number.

It is important physical quantity and useful in the determination of mass attenuation coefficient, radiation dosimetry and other parameters. The work is useful for the medical, radiation therapy, shielding, space radiation.

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