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Evaluation of radiological data of some saturated fatty acids using gamma ray spectrometry

Prashant S. Kore [a,*], Pravina P. Pawar [a], T Palani Selvam [b]

[a] *Department of Physics, Dr.Babasaheb Ambedkar Marathwada University, Aurangabad: 431 004. India*
[b] *Radiological Physics and Advisory Division, Bhabha Atomic Research Centre, Mumbai*

HIGHLIGHTS

- Compute the values of mass attenuation coefficient (μ_m) of saturated fatty acids.
- The values of (μ_{en}/ρ) i.e mass energy-absorption coefficient are calculated.
- Comparison of all (μ/ρ) and (μ_{en}/ρ) values with Win-Xcom program.
- The measured data are useful in radiation dosimetry and other fields.

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ABSTRACT

Radiological parameters such as mass attenuation coefficients (μ_m), total attenuation cross section (σ_{tot}), molar extinction coefficient (ε), mass energy absorption coefficient (μ_{en}/ρ) and effective electronic cross section ($\sigma_{t,\,el}$) of saturated fatty acids, namely butyric acid ($C_4H_8O_2$), caproic acid ($C_6H_{12}O_2$), enanthic acid ($C_7H_{14}O_2$), caprylic acid ($C_8H_{16}O_2$), pelargonic acid ($C_9H_{18}O_2$) and valeric acid ($C_5H_{10}O_2$) were measured using NaI(Tl)-based gamma spectrometry. Radioactive sources used in the study are ^{57}Co, ^{133}Ba, ^{137}Cs, ^{54}Mn, ^{60}Co and ^{22}Na. Gamma ray transmission method in a narrow beam good geometry set up was used in the study. The measured data were compared against Win-XCOM-based data. The agreement is within 1%.

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1. Introduction

Knowledge of absorption, penetration, attenuation and photon interactions with biological material such as amino acids, fatty acids, lipids and carbohydrates is essential in radiation medicine and biology, nuclear technology and space research (Jakson and Hawkes, 1981). The study of photon interactions with matter is important and the data on the transmission and absorption of X-rays and gamma rays in biological shielding and dosimetric materials assumed great significance by virtue of the diverse application in the field of medical physics and medical biology (Kaewkhao et al., 2008). A variety of physiological functions inside living system are performed by complex molecules such as fatty acids, carbohydrates, and proteins compose of H, C, N, and O element. Mass attenuation coefficient (μ_m) and mass energy absorption coefficient (μ_{en}/ρ) of photons in matter play an important role in understanding attenuation and energy absorption. Seltzer (1993) reported μ_{en}/ρ data for elements, compound and mixtures as a function of energy of photons. Hubbell (1999) carried out a review of photon interaction cross section data in the medical and biological context. Selection of material for radiation shielding and protection needs an accurate assessment of interaction parameters Teli et al., (2001). In addition to μ_m and μ_{en}/ρ, the parameters such as Zeff (effective atomic number), σ_{tot} (total attenuation cross section), ε (molar extinction coefficient), and $\sigma_{t,el}$ (effective electronic cross section) of complex molecules of biological interest also play an important role in understanding dosimetry of photons. The calculation of Z_{eff} is based on the parameterization of the photon interaction cross-section by fitting data over limited ranges of photon energies and atomic number Jackson and Hawkes (1981). Gerward et al. (2001) and Sandhu et al. (2002) reported molar extinction coefficient for fatty acids. Gerward et al. (2004) and Berger, Hubbell (1987) investigated photon attenuation in elements and arbitrary materials.

Several published studies such as Kirby et al. (2003), Midgley

* Corresponding author at: Dept. of Physics, Dr. Babasaheb Ambedkar Marathwada University Aurangabad, Aurangabad-431004 (M.S.).
E-mail addresses: koreprashant33@gmail.com (P.S. Kore), Pravina.pawar@yahoo.com (P.P. Pawar).

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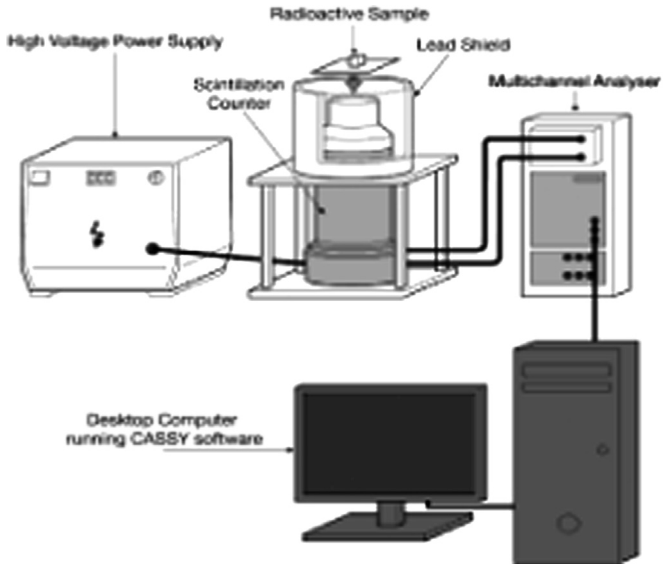

Fig. 1. The schematic view of the experimental set up.

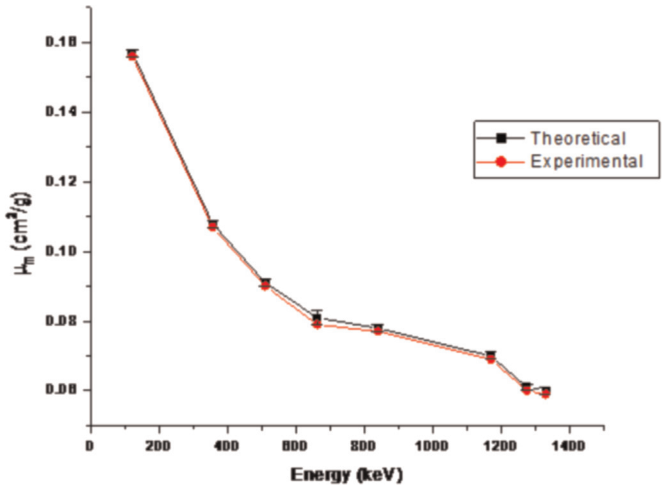

Fig. 2. Plot of mass attenuation coefficient (μ_m) versus photon energy for butyric acid ($C_4H_8O_2$).

Table 1
Mean atomic numbers (Z) calculated from the chemical formula for fatty acids.

Saturated fatty acids	Molar mass (g/mol)	Chemical Formula	Z
Butyric acid	088.105	($C_4H_8O_2$)	3.42
Caproic acid	116.158	($C_6H_{12}O_2$)	3.20
Enanthic acid	130.185	($C_7H_{14}O_2$)	3.13
Caprylic acid	144.212	($C_8H_{16}O_2$)	3.07
Pelargonic acid	158.239	($C_9H_{18}O_2$)	3.03
Valeric acid	169.517	($C_5H_{10}O_2$)	3.29

(2004, 2005), Shivaramu et al. (2001a, 2001b), Sandhu et al. (2002), Gowda et al. (2004, 2005), Manjunathaguru and Umesh (2006), Manohara and Hanagodimath (2007) and El-Kateb and Abdul-hamid (1991) were devoted on the investigation of above parameters. There have been a number of experimental and theoretical investigations by Pawar and Bichile (2013), Kore and Pawar (2014), Ladhaf and Pawar (2015), Baltas, Cevik (2008) to determine mass attenuation coefficients for complex biological molecules such as Lipids, Carbohydrates, Proteins, Fats and Oils composed of H, C, N and O elements in varying proportions.

The present work is aimed at measuring the radiological parameters of photons such as μ_m, σ_{tot}, ε, μ_{en}/ρ and $\sigma_{t,el}$ for several fatty acids using the NaI(Tl)–based gamma ray spectrometry. The saturated fatty acid samples used in the study are butyric acid ($C_4H_8O_2$), caproic acid ($C_6H_{12}O_2$), enanthic acid ($C_7H_{14}O_2$), caprylic acid ($C_8H_{16}O_2$), pelargonic acid ($C_9H_{18}O_2$) and valeric acid ($C_5H_{10}O_2$). Radioactive sources used in the study are ^{57}Co, ^{133}Ba, ^{137}Cs, ^{54}Mn, ^{60}Co and ^{22}Na.

2. Theory

In this section we summarize some theoretical relations that have been used for the determination of (μ_m) in the present work. When a monochromatic beam of gamma photons is incident on a target, some photons are emitted due to the dominant interaction processes and therefore, the transmitted beam is attenuated. The extent of attenuation depends on given elemental target. This attenuation of the beam is described by the following equation:

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

Where, I_0 and I are the incident and transmitted photon intensities, respectively, μ (cm^{-1}) is the linear attenuation coefficient of the material and t (cm) is the sample thickness. Rearrangement of Eq. (1) yields the following equation for the linear attenuation coefficient:

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

The values of μ_m (cm^2 g^{-1}) for the samples were obtained from Eq. (3) by using the density of the corresponding samples:

$$\mu_m = \frac{\mu}{\rho}\left(cm^2 g^{-1}\right) = \frac{1}{\rho t}\ln\left(\frac{Io}{I}\right) \quad (3)$$

where, ρ (g/cm^3) is a measured density of the corresponding sample. The values of μ_m were then used to determine σ_{tot} by the

Table 2
Comparison of measured and calculated values of mass attenuation coefficient μ_m (cm^2/g) of fatty acids at different photon energies. The calculated values are based on WinXCOM program.

Sr.	Fatty	122 keV		356 keV		511 keV		662 keV		835 keV		1173 keV		1275 keV		1332 keV		Error
no.	acids	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	The	Exp.	Theo.	
1	Butyric acid	0.156	0.157	0.107	0.108	0.090	0.091	0.079	0.081	0.077	0.078	0.069	0.070	0.060	0.061	0.059	0.060	0.001
2	Caproic acid	0.157	0.159	0.107	0.109	0.09	0.092	0.08	0.082	0.077	0.079	0.068	0.070	0.053	0.055	0.052	0.054	0.002
3	Enanthic acid	0.157	0.159	0.107	0.109	0.09	0.092	0.08	0.082	0.077	0.079	0.069	0.071	0.053	0.055	0.053	0.055	0.002
4	Caprylic acid	0.158	0.160	0.107	0.109	0.091	0.092	0.080	0.082	0.077	0.079	0.069	0.071	0.053	0.055	0.053	0.055	0.002
5	Pelargonic acid	0.158	0.160	0.107	0.109	0.091	0.093	0.081	0.083	0.080	0.082	0.077	0.079	0.071	0.073	0.053	0.055	0.002
6	Valeric acid	0.156	0.158	0.107	0.109	0.089	0.091	0.076	0.078	0.079	0.081	0.068	0.070	0.053	0.055	0.052	0.054	0.002

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