Two Gamma Spectrometric Parameters of Two Organic Liquids with Various Beams Geometry Collimators

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Abstract

The mass attenuation coefficients of two organic liquids (ethanol and acetone) have been examined by using NaI(Tl) scintillation detector. The gamma sources used are ^{22}Na (511 keV and 1275 keV), ^{137}Cs (662 keV) and ^{60}Co (1173 keV and 1332 keV). In this research, three beam geometrical configurations (narrow beam, semi-broad beam and broad beam) were constructed by six lead collimators. The main focus of this study is to determine the attenuation properties of two organic liquids containing H, C and O. The mass attenuation coefficients and the atomic cross - sections of two organic liquids were determined theoretically by using the mixture rule and experimentally by using gamma-ray attenuation technique. The experimental mass attenuation coefficients were found to be in nearly agreement with the theoretical values in narrow beam and first semi-broad beam geometries. The total atomic cross-sections of two organic liquids were calculated.

Introduction

Gamma transmission methods have been developed for environmental research in soil science and hydrology. There are three gamma spectrometric parameters (mass attenuation coefficient (μ/ρ), atomic across section (σ) and effective atomic number (Z_{eff})) in the gamma attenuation technique. The aim of the research is to determine two gamma spectrometric parameters (mass attenuation coefficient and atomic across section) of two industrial organic liquids.

Since the photon attenuation coefficient is an important parameter characterizing the penetration and diffusion of gamma rays in complex media. The determination of mass attenuation coefficients and atomic cross-sections of two organic liquids using various beam geometry collimators in this research is applicable in finding attenuation coefficients for other organic liquids.

Ethanol, also known as ethyl alcohol, drinking alcohol or grain alcohol, is a flammable, colorless, slightly toxic chemical compound with a distinctive perfume-like odor. Its molecular formula is C_2H_5OH. Ethanol is used extensively as a solvent in the manufacture of varnishes and perfumes, as a preservative for biological specimens, in the preparation of essences

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and flavorings, in many medicines and drugs, as a disinfectant and in tinctures and as a fuel and gasoline additive. Heavy consumption of alcohol, however, may cause addiction and increases all types of injury and trauma. Environmental and genetic factors are involved in susceptibility to alcoholism.

Acetone is the simplest representative of the ketones. It is readily soluble in water, ethanol, ether, etc., and itself serves an important solvent. Its molecular formula is CH_3COCH_3. Acetone is also used as a superglue remover and can be used for thinning and cleaning fiberglass resins and epoxies. It is a strong solvent for most plastics and synthetic fibers. Acetone is extremely effective when used as a cleaning agent when dealing with permanent markers. Another industrial application is to use it as a general purpose cleaner in paint and ink manufacturing operations. Acetone is an irritant and inhalation may lead to hepatotoxic effects causing liver damage. The fumes should be avoided. It can cause permanent eye damage. Pregnant women should avoid contact with acetone and acetone fumes in order to avoid the possibility of birth defects, including increased brain damage. [Dagli S et.al]

Theoretical Background

Theoretical mass attenuation coefficient and atomic cross section

The mass attenuation coefficients for compounds are usually estimated from the sum of the weighted contributions of the constituent elements. This is based on the assumption that the contribution of each element to the attenuation is additive and is known as the mixture rule. The absorbing material to be a mixture of materials or a solution, the mass attenuation coefficient is given by the weighted average. [Tsoulfanidis N]

$$(\mu/\rho)_{material} = \sum_j (\mu/\rho)_j \, w_j \quad (\sum w_j = 1)$$

$(\mu/\rho)_{material}$ = the mass attenuation coefficient of the absorbing material

w_j=the weight fraction of the constituent j having mass attenuation coefficient $(\mu/\rho)_j$

The calculated mass attenuation coefficients are represented in Table (1).The calculated atomic cross section data are also listed in Table (2).

Table (1) The calculated mass attenuation coefficients

Liquids	$\mu/\rho_{(Theo)}$ (cm^2/g)				
	511keV	662keV	1173keV	1275keV	1332keV
Ethanol	0.0974	0.0870	0.0663	0.0652	0.0621
Acetone	0.0951	0.0850	0.0648	0.0637	0.0607

Total atomic cross section

The total atomic cross-section of the absorbing material can be written as follows. [Tsoulfanidis N]

$$\sigma_j = \frac{(\mu/\rho)_{material}}{N_A \sum_j \frac{w_j}{A_j}}$$

A_j= the atomic weight of the element in the material

w_j = the fractional weights of the material

Table (2) The calculated atomic cross section data

Liquids	σ (barn/atom)				
	511keV	662keV	1173keV	1275keV	1332keV
Ethanol	0.0807	0.0721	0.0563	0.0554	0.0527
Acetone	0.0774	0.0691	0.0624	0.0614	0.0584

Materials and Methods

To know the gamma attenuation in organic liquid, the experiments were done by the following procedure. The two liquids were collected from Academy Chemical Group. The liquid sample was placed in a glass container which was used as an absorber. To calculate the density of organic liquid, firstly the empty glass was weighed on the balance. The total weight of organic liquid with the glass container was recorded. Then the masses of organic liquids were obtained. Volume of each organic liquid was 180 cm^3. Therefore the densities of organic liquids were calculated. The average of the measurements was taken in order to minimize statistical error. The measured densities of the two liquids were carefully determined from the relation $\rho = \frac{1}{N}\sum_{i=1}^{N}\rho_i$ and in the following procedures as shown in Table (3).

Table (3) The measured densities of two organic liquids

Mass (g)					Density (g/cm^3)	
Empty glass	Glass + ethanol	Ethanol	Glass + acetone	Acetone	Ethanol	Acetone
519.85 ± 0.0085	663.40 ± 0.0825	143.55 ± 0.0085	659.50 ± 0.0081	139.6 5 ± 0.0078	0.80 ± 0.0009	0.78 ± 0.0008

Six Lead Collimators

The used six lead collimators in this research have been performed in the following steps. Firstly, three tin cups of 4cm long had been ordered to mould into lead at tinsmith's workshop. Secondly, some lead had been poured into them at Shwenandaw Battery shop. Then the three lead moulds had been made holes in the middle of each at lathe. They were pierced 1cm, 1.5cm and 2cm diameter in each one. Finally they were cut into half of 2cm length.To demonstrate the collimation effects on organic liquids, the various diameters of collimators (six lead blocks) were used. They are two lead collimators of 1cm diameter, two lead collimators of 1.5cm diameter and two lead collimators of 2 cm diameter. All lead collimators are in length 2cm.The front views of the collimators were shown in Figures (1), (2) and (3).

Figure (1) Photograph of two lead collimators in 1cm

Figure (2) Photograph of two lead collimators in 1.5 cm

Figure (3) Photograph of two lead collimators in 2 cm

Three Beam Geometrical Configurations

Measurement of attenuation of photons in material can be categorized as either narrow beam or broad beam attenuation measurements. The narrow beam attenuation geometry can in principle be achieved by an arrangement, which prevents the scattered, and the secondary radiations from reaching the detector. On the other hand, the broad beam attenuation occurs in the case of any geometry other than narrow beam. In each measurement of attenuation effect on these liquids, the diameters of the collimators for the source and the detector were selected different values in the experiments. [Kateb A]

For the narrow beam geometry, the diameter of collimators was adjusted to 1cm.

For narrow beam geometry

The diameter of the source collimator	The diameter of the detector collimator
1cm	1cm

For semi-broad beam geometry, the diameters of the collimators for the source and the detector were selected in different values as seven pairs.

For seven semi-broad beam geometries

Geometrical Configuration	The diameter of the source collimator	The diameter of the detector collimator
First semi-broad beam	1cm	1.5cm
Second semi-broad beam	1cm	2cm
Third semi-broad beam	1.5cm	1cm
Fourth semi-broad beam	1.5cm	1.5cm
Fifth semi-broad beam	1.5cm	2cm
Sixth semi-broad beam	2cm	1cm
Seventh semi-broad beam	2cm	1.5cm

For broad beam geometry, the diameter of collimators was adjusted to 2cm.

For broad beam geometry

The diameter of the source collimator	The diameter of the detector collimator
2cm	2cm

Experimental Set-up

In gamma ray spectrometry system, the following equipments are included. They are NaI (Tl) scintillation detector associated with ORTEC (Model 296) photomultiplier tube, high voltage power supply, preamplifier (Model 142 PC), fast spectroscopy amplifier (Model 671), a pulse stored multi-channel analyzer (MCA) together with Gamma Vision 32 software installed in PC. The high voltage power supply was used for supplying the potentials for the detector. The operating voltage for NaI (Tl) scintillation detector is 1000V. The 3" x 3" NaI (Tl) Scintillation detector was used to detect the gamma radiation intensity before and after passing though the absorbing material and this information (electronic pulses) was amplified and stored in MCA based on personal computer.[ORTEC Software and Manual]

This horizontal experimental setting was fixed for throughout the whole research laboratory measurement. In this research, the gamma sources ^{22}Na (activity = 1μCi, half-life = 2.6 years, energy = 511.00 keV and 1274.54 keV), ^{60}Co (activity = 1μCi, half-life = 5.27 years, energy = 1173.23 keV and 1332.49 keV) and ^{137}Cs (activity = 1μCi, half-life = 30.2 years, energy = 661.65 keV) were used for energy calibration. The lead (Pb) shielding was used to shield cosmic rays and other radiations in environment. In this work, conversion gain was set at 2048.Coarse gain was fixed at 20 and fine gain was 0.794. Shaping time was 1 μ second. Real time was set at 2500 seconds and live time was set at 1800 seconds.

Six lead collimators were used to show collimation effects on narrow beam geometry, semi-broad beam geometry and broad-beam geometry. The distance between the source and the detector was fixed at 14cm.

The total mass attenuation coefficients of two liquids were measured by using $I=I_0 e^{-\mu t}$ equation for gamma transmission experiments in different collimators of various diameters measurements. The thickness of the liquid in the container was 9.319±0.0008 cm.

. Spectra were recorded with and without the absorber assuming the area measured under the peak for the absorber as I and the area measured under the peak for the absence of absorber as I_0. The block diagram of experimental set-up was as shown in Figure (4).Also the front views of the experimental set-up was illustrated in Figure (5).

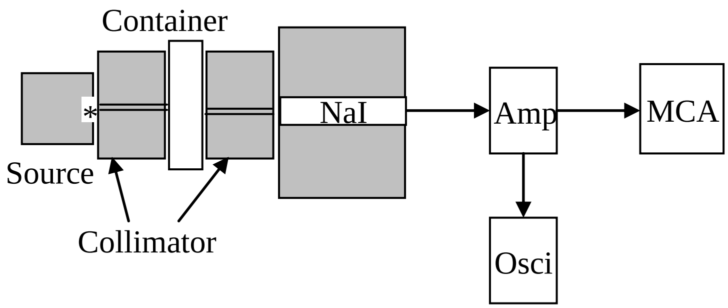

Figure (4) Block diagram of Experimental-Set up

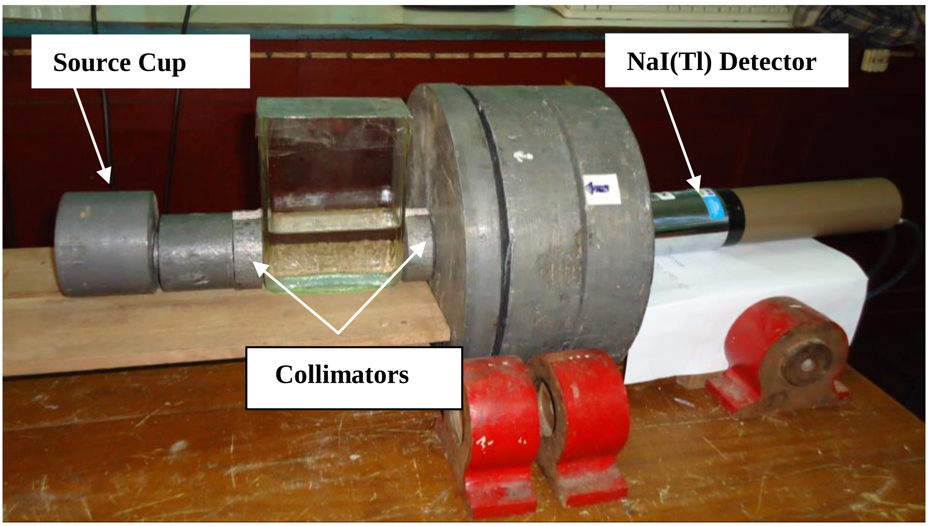

Figure (5) Photograph of Experimental-Set up

Results and Discussion

I_0 and I for ethanol and acetone are shown in Table (4) and Table (5).According to $I = I_0\ e^{-\mu t}$ and density, the experimental mass attenuation coefficients of the two organic liquids are listed in Table (6) and Table (7) for various collimators. The experimental atomic cross sections are also obtained from these values and are represented in Table (8) and Table (9).

As shown in Tables (6) and (7), the experimental mass attenuation coefficients are closer to theoretical values at narrow beam (1 cm-1 cm) and first semi-broad beam (1 cm-1.5 cm) than other beam geometries. The measured mass attenuation coefficients from narrow beam and first semi-broad beam geometries decrease as the photon energy increases.

It can be seen from the experimental results for two organic liquids, the variation of (μ/ρ) with energy is more or less similar. It can be found that theoretical mass attenuation coefficients are nearly agreement with the experimental mass attenuation coefficients from narrow beam (1 cm-1 cm) and first semi-broad beam (1 cm-1.5 cm) geometry results.

The total atomic cross-sections were obtained for the mass attenuation coefficient. The atomic cross sections have similar differences between measured and calculated values as the mass attenuation coefficients due to the counting statistics, thickness determination and errors in interpolation.

As illustrated in Figures (7) and (10), the mass attenuation coefficient values from seven semi-broad beam geometries are more or less similar with the narrow beam values. However the values from first semi-broad beam are nearly agree with the narrow beam values. The broad beam experiments were also done in order to determine the optimum diameter of the collimators As a result, if the diameters of collimators are selected as small as possible the semi-broad beam geometry can be used in some situations that are difficult to provide narrow beam geometry.

All gamma sources in the Experimental Nuclear Physics Laboratory, Department of Physics, Mandalay University are isotropic and have low activity, the diameter of the collimator should be at least 1cm diameter dimension in any experiments. Therefore the diameter of the source collimator - the diameter of the detector collimator (1 cm-1 cm) position is most suitable among various beam geometrical configurations.

Table (4) The analyzed I_0/I data for Ethanol

Diameter of the source collimator	Diameter of the detector collimator	I_0/I				
		511 keV	662 keV	1173 keV	1275 keV	1332 keV
1cm	1cm	2.0017	1.8549	1.7498	1.6473	1.4578
1cm	1.5cm	1.9704	1.9029	1.6982	1.4879	1.4851
1cm	2cm	1.9689	1.6383	1.6474	1.3876	1.4450
1.5m	1cm	2.1074	1.9607	1.5734	1.9439	1.4677
1.5cm	1.5cm	2.1667	2.0521	1.6251	1.6134	1.7163
1.5cm	2cm	2.0776	1.7652	1.5295	1.3744	1.4951
2cm	1cm	1.9224	2.0725	1.7784	1.6601	1.5776
2cm	1.5cm	2.1958	2.2089	1.7141	1.6245	1.7221
2cm	2cm	2.1837	1.9535	1.3358	1.5324	1.6291

Table (5) The analyzed I_0/I data for Acetone

Diameter of the source collimator	Diameter of the detector collimator	I_0/I				
		511 keV	662 keV	1173 keV	1275 keV	1332 keV
1cm	1cm	2.0498	1.8317	1.6418	1.5320	1.4741
1cm	1.5cm	1.9335	1.8562	1.6107	1.4653	1.4571
1cm	2cm	1.8465	1.7604	1.6229	1.5655	1.6531
1.5m	1cm	1.7757	1.8273	1.5734	1.7733	1.4610
1.5cm	1.5cm	1.9706	1.9731	1.9748	1.4776	1.7323
1.5cm	2cm	2.0889	1.9285	1.6785	1.4692	1.4986
2cm	1cm	2.0795	1.8944	1.5154	1.7755	1.3630
2cm	1.5cm	1.9229	1.9071	1.6317	1.6531	1.4174
2cm	2cm	2.0032	1.8314	1.3684	1.4271	1.4810

Table (6) The experimental mass attenuation coefficient data for Ethanol

Diameter of the source collimator	Diameter of the detector collimator	$\mu/\rho_{(Expt)}$ (cm^2/g)				
		511 keV	662 keV	1173 keV	1275 keV	1332 keV
1cm	1cm	0.0931 ± 0.0089	0.0829 ± 0.0023	0.0750 ± 0.0029	0.0669 ± 0.0039	0.0506 ± 0.0039
1cm	1.5cm	0.0910 ± 0.0078	0.0863 ± 0.0016	0.0710 ± 0.0030	0.0533 ± 0.0039	0.0530 ± 0.0029
1cm	2cm	0.0909 ± 0.0076	0.0662 ± 0.0016	0.0670 ± 0.0024	0.0439 ± 0.0037	0.0494 ± 0.0029
1.5m	1cm	0.0997 ± 0.0095	0.0903 ± 0.0020	0.0608 ± 0.0033	0.0892 ± 0.0027	0.0515 ± 0.0033
1.5cm	1.5cm	0.1037 ± 0.0087	0.0964 ± 0.0014	0.0651 ± 0.0026	0.0642 ± 0.0033	0.0725 ± 0.0023
1.5cm	2cm	0.0981 ± 0.0080	0.0762 ± 0.0013	0.0570 ± 0.0026	0.0427 ± 0.0041	0.0539 ± 0.0028
2cm	1cm	0.0877 ± 0.0088	0.0978 ± 0.0018	0.0772 ± 0.0030	0.0680 ± 0.0034	0.0612 ± 0.0038
2cm	1.5cm	0.1055 ± 0.0087	0.1063 ± 0.0013	0.0723 ± 0.0028	0.0651 ± 0.0034	0.0729 ± 0.0027
2cm	2cm	0.1048 ± 0.0084	0.0898 ± 0.0012	0.0388 ± 0.0039	0.0573 ± 0.0028	0.0655 ± 0.0023

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Table (7) The experimental mass attenuation coefficient data for Acetone

Diameter of the source collimator	Diameter of the detector collimator	$\mu/\rho_{(Expt)}$ (cm^2/g)				
		511 keV	662 keV	1173 keV	1275 keV	1332 keV
1cm	1cm	0.0987 ± 0.0026	0.0833 ± 0.0023	0.0682 ± 0.0033	0.0587 ± 0.0047	0.0534 ± 0.0039
1cm	1.5cm	0.0907 ± 0.0017	0.0851 ± 0.0016	0.0656 ± 0.0033	0.0526 ± 0.0047	0.0518 ± 0.0028
1cm	2cm	0.0844 ± 0.0015	0.0778 ± 0.0015	0.0666 ± 0.0025	0.0617 ± 0.0036	0.0692 ± 0.0025
1.5m	1cm	0.0790 ± 0.0034	0.0829 ± 0.0022	0.0700 ± 0.0032	0.0788 ± 0.0035	0.0528 ± 0.0034
1.5cm	1.5cm	0.0933 ± 0.0018	0.0935 ± 0.0015	0.0936 ± 0.0021	0.0995 ± 0.0030	0.0756 ± 0.0023
1.5cm	2cm	0.1014 ± 0.0014	0.0904 ± 0.0013	0.0713 ± 0.0023	0.0529 ± 0.0041	0.0557 ± 0.0029
2cm	1cm	0.1007 ± 0.0027	0.0879 ± 0.0020	0.0572 ± 0.0038	0.0790 ± 0.0036	0.0426 ± 0.0047
2cm	1.5cm	0.0900 ± 0.0018	0.0888 ± 0.0014	0.0674 ± 0.0030	0.0692 ± 0.0038	0.0480 ± 0.0037
2cm	2cm	0.0956 ± 0.0014	0.0832 ± 0.0013	0.0432 ± 0.0039	0.0489 ± 0.0034	0.0540 ± 0.0027

Table (8) The experimental atomic cross section data for Ethanol

Diameter of the source collimator	Diameter of the detector collimator	σ (barn/atom)				
		511 keV	662 keV	1173 keV	1275 keV	1332 keV
1cm	1cm	0.0790	0.0704	0.0637	0.0568	0.0430
1cm	1.5cm	0.0773	0.0733	0.0603	0.0452	0.0450
1cm	2cm	0.0771	0.0562	0.0569	0.0373	0.0419
1.5m	1cm	0.0846	0.0766	0.0516	0.0757	0.0437
1.5cm	1.5cm	0.0880	0.0818	0.0553	0.0545	0.0615
1.5cm	2cm	0.0833	0.0647	0.0484	0.0362	0.0458
2cm	1cm	0.0744	0.0830	0.0655	0.0577	0.0519
2cm	1.5cm	0.0900	0.0902	0.0614	0.0553	0.0619
2cm	2cm	0.0889	0.0762	0.0330	0.0486	0.0556

Table (9) The experimental atomic cross section data for Acetone

Diameter of the source collimator	Diameter of the detector collimator	σ (barn/atom)				
		511 keV	662 keV	1173 keV	1275 keV	1332 keV
1cm	1cm	0.0951	0.0803	0.0657	0.0566	0.0515
1cm	1.5cm	0.0874	0.0820	0.0632	0.0507	0.0500
1cm	2cm	0.0813	0.0750	0.0642	0.0595	0.0667
1.5m	1cm	0.0761	0.0799	0.0675	0.0759	0.0509
1.5cm	1.5cm	0.0899	0.0901	0.0902	0.0959	0.0728
1.5cm	2cm	0.0970	0.0871	0.0687	0.0510	0.0537
2cm	1cm	0.0867	0.0847	0.0551	0.0761	0.0410
2cm	1.5cm	0.0921	0.0856	0.0650	0.0666	0.0462
2cm	2cm	0.0916	0.0802	0.0416	0.0471	0.0520

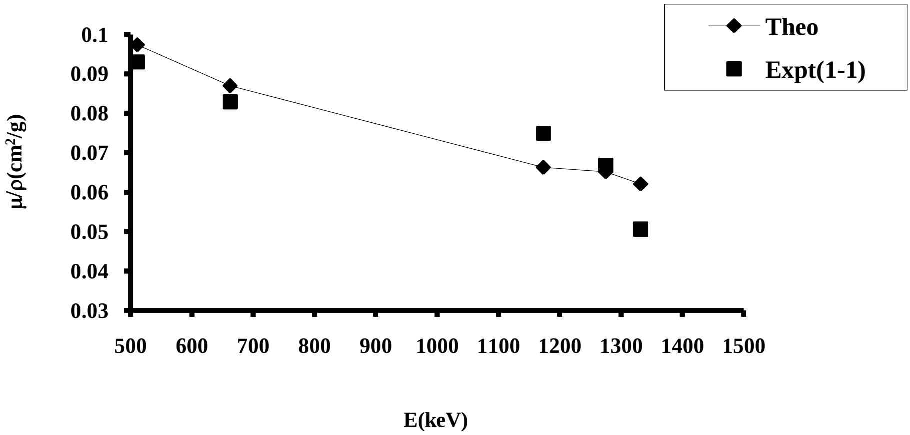

Figure (6) The comparison of μ/ρ $_{(Theo)}$ and μ/ρ $_{(Expt)}$ at narrow beam geometry for ethanol as a function of photon energy

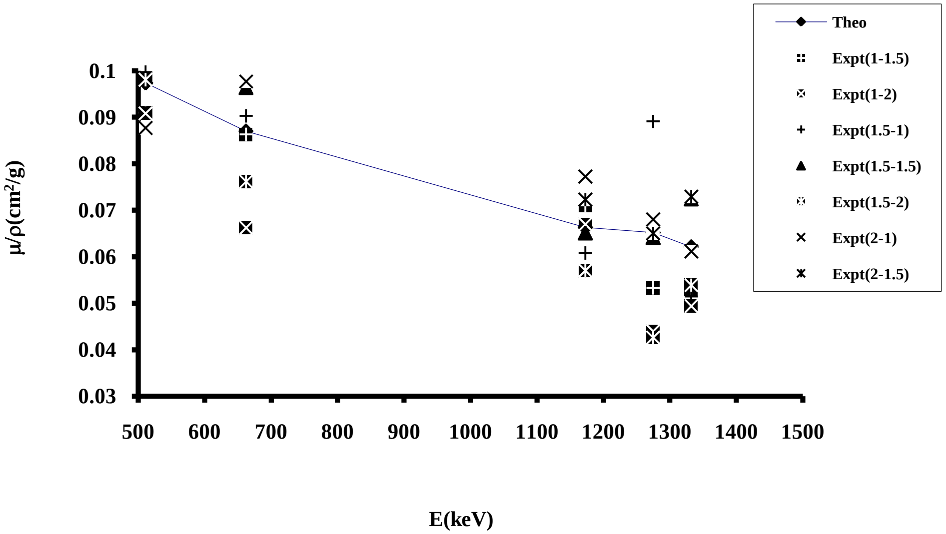

Figure (7) The comparison of μ/ρ $_{(Theo)}$ and μ/ρ $_{(Expt)}$ at seven semi-broad beam geometries for ethanol as a function of photon energy

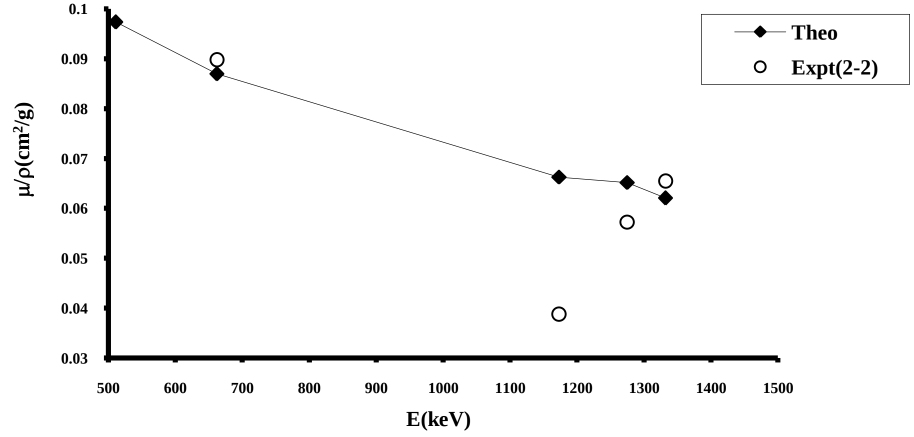

Figure (8) The comparison of $\mu/\rho_{(Theo)}$ and $\mu/\rho_{(Expt)}$ at broad beam geometry for ethanol as a function of photon energy

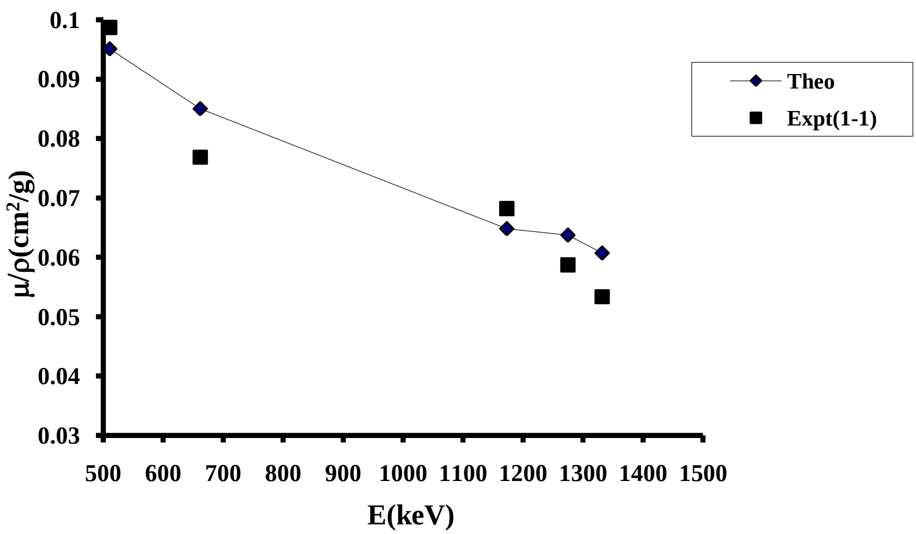

Figure (9) The comparison of $\mu/\rho_{(Theo)}$ and $\mu/\rho_{(Expt)}$ at narrow beam geometry for acetone as a function of photon energy.

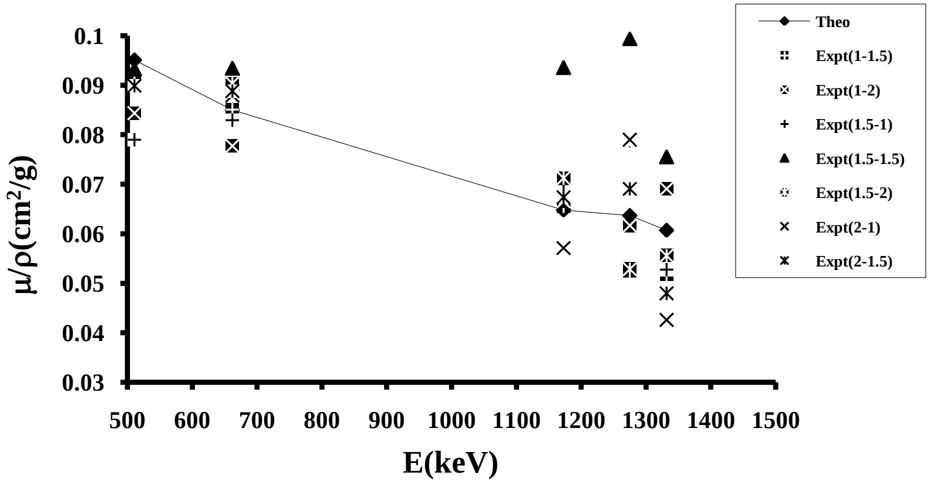

Figure (10) The comparison of $\mu/\rho_{\text{(Theo)}}$ and $\mu/\rho_{\text{(Expt)}}$ at seven semi-broad beam geometries for acetone as a function of photon energy

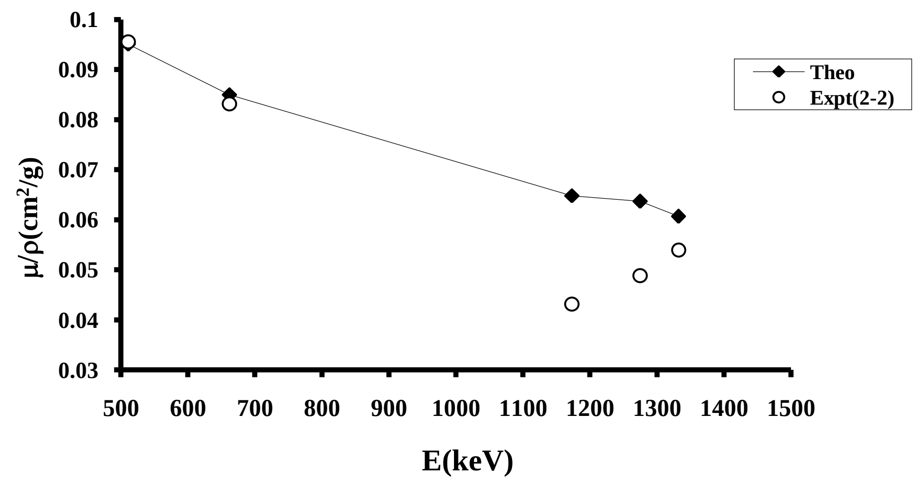

Figure (11) The comparison of $\mu/\rho_{\text{(Theo)}}$ and $\mu/\rho_{\text{(Expt)}}$ at broad beam geometry for acetone as a function of photon energy.

Conclusion

The organic liquids in this study are composed of elements with Z< 20 and the variation in the total mass attenuation coefficient at the studied photon energies is seen to be negligible. The solvent substance interacts with the gamma electromagnetic radiation in a different manner than when they are separated. The liquids in this study contain H, C and O and then chemical compositions are quite similar. Therefore the mass attenuation coefficients of organic liquids do not differ significantly by chemical compositions.

By using the collimator's flux of radiation intensity and quantity of radiation, as a consequence, the absolute values such as the gamma spectrometric parameters (mass attenuation coefficient, atomic cross section and effective atomic number) can be calculated. A commonly used method of obtaining an effective atomic number (Z_{eff}) of a material consisting of different elements in definite proportions is based on the determination of total mass attenuation coefficient (μ/ρ) for gamma ray interaction by the transmission method. The effective atomic number (Z_{eff}) is a very useful parameter for technology, nuclear industry, space research programs, engineering and in many fields of scientific applications. The fact is of importance for environmental research in soil science and hydrology.

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