التفاعل المتبادل بين إشعاعات جاما والمادة

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ملخص البحث :

الهدف من هذه التجربة هو دراسة تفاعل أشعة جاما مع المادة من خلال ثلاث عمليات، وتشمل هذه الامتصاص الكهروضوئي، وتشتت كومبتون، وإعداد إنتاج الزوج. تتألف هذه التجربة من كاشف جرمانيوم عالي النقاء (HPGe) مع طاقة تتراوح بين [121 keV - 1408 keV] ومحلل متعدد القنوات (MCA). لقد أظهرت نتائج الرسم البياني أن الفوتون الساقط يفقد شدته مع كل زيادة في الامتصاص، و يعتمد معدل حدوث ذلك على مادة الامتصاص والعدد الذري Z. أشعة جاما حيث يظهر أنها تتبع قانون ألبير حيث تم العثور على معامل توهين الكتلة لكل ذروة طاقة 153 Eu ينخفض مع زيادة طاقة الذروة. من التجربة التي تم إعدادها باستخدام مطياف بلوري نال (TI) ، ومصدر C137 لإنتاج أشعة جاما بطاقة 662 kev. تم التحقيق في تشتت كومبتون بتفاعل الفوتون مع الإلكترونات الحرة. ينحرف بزاوية بالاتجاه الصحيح، ونتيجة لذلك تم قياس تشتت كومبتون من قضيب الألومنيوم بواسطة إشعاع متناثر، تم الحصول على العلاقة بين الإشعاع المتناثر لعد الطاقة مقابل الزاوية. تم اكتشاف أن الزاوية منخفضة و كانت القيمة المقاسة أقل مما متوقع من صيغة كلاين- نيشينا ولكن تميل إلى الالتقاء عند قيم أعلى لزاوية الدوران. يمكن أن نرى بوضوح من هذه النتائج أن عدد الطاقة ينخفض مع زيادة زاوية الانتثار، باستخدام هذه البيانات، تم برسم العلاقة البيانية لـ $1 / E\gamma$ مع $(\cos\theta-1)$. النتيجة في خط مستقيم مع اعتراض (1.5114 ±) وتدرج (1.9522 ±) وقد كانت متوافقة جيدًا مع النظرية. .

Experiment of Compton Scattering and Attenuation

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Abstract

The aim of this experiment was become familiarized to study the interaction of gamma-rays with matter through three processes, these include photoelectric absorption, Compton scattering, and pair production set-up. This consisted of a high purity germanium (HPGe) detector with energy between [121 keV-1408 keV] rang and a Multichannel Analyzer (MCA) a radioactive source and absorber to calibration. The results of the graph show that an incident photon loses its intensity with every increase in the absorber. The rate at which this happens depends on the absorber material and the atomic number Z. the gamma rays where shown to follow beers law where the mass attenuation coefficient for each peak energy of^{153} Eu was found to decrease as the peak energy increase. The second part of the experiment was set up by using a Nal (TI) scintillation crystal spectrometer, and 137Cs source to produce γ-ray with energy 662kev. The Compton scattering was investigated the interaction of photon with free electrons. It is deflected through an angle with right direction, as a result the Compton scattering from the aluminium rod was measured by scattered radiation. The relation between the scattered radiations of energy count versus the angle was obtained. It was discovered that low angle the measured value fell below the prediction of klein- Nishina formula but it tend to meet at higher values of the rotation angle. It can be seen clearly from these results that the energy count decrease as the scattering angle increase, by using these data, the graph of 1/Eγ a giant (1-cosθ) was plotted. The

result was in straight line with intercept of (1.5114 ±) and gradient of (1.9522±) that were good agreement with theory.

Key words - gamma rays, scattering, Photoelectric, photon, Mass attenuation coefficient.

1. Introduction

In general, gamma rays are electromagnetic radiations that were emitted from nuclear of excitation, which is an interaction electron with nucleus, absorbs the excitation energy from the nucleus, and ejected from the atom [1]. The transmission of gamma ray energy to the matter differs from that of charged particles, these are three major types of natural interaction mechanisms which are known for gamma-rays, photon electric effect, Compton scattering and pair production of these there interactions is depend on the energy of the incident photon atomic number and atomic structure of the matter. In addition, in three processes the photon ether absorption or scattering away from its original direction in single interaction [3].

The purpose of this experiment is to determine γ-ray scattering and the attenuation of gamma ray. The attenuation will be studied the effect of material thickness on the energy of gamma-ray. Compton scattering will be investigated the scattering of gamma-rays by aluminum rod. The characteristics of photon interaction with matter was shown by plotting the relation between the energy of each peak, which were measured, and calculated mass attenuation coefficient for each peak. Finally, the differential scattering cross section will be studied the theoretical and experimental data. All the results will be presented and discussed.

2. Theory

The atom consists of nucleus surrounded by electrons that rotate around it. Gamma radiations emitted by a radioactive source, knowledge of basic process by which a photon interacts with matter, that have energies typically in the range of 1 to 10 MeV, the energy difference between nuclear state, and corresponding wavelengths, and gamma spectroscopy are essential to understand the response of scintillation detector. There are three important gamma-rays absorption process when gamma-rays interaction with matter, these are photoelectric effect, Compton scattering, and pair production effect [1-4].

2.1 Photoelectric Effect

Photoelectric is produced from one of the electron shells of the atom, in this interaction the gamma ray photon absorbed completely, and the energy will be transmitted to the electron. It can be seen the photoelectron is emitted from (K) shall. In addition, this interaction is proportional effect increases with increasing the atomic number to atomic number of the absorber (Z) which means that the photoelectric effect increases with increasing the atomic number [2-4].

2.2 Compton Effect

Compton effect is the interaction of the photon with a free electron which is binding energy is very small. The photon collides with a free electron found the scattered photon must have less energy, and the difference between the incident and scattered photon is transferred to the free electron, as a result the electron will recoil with a kinetic energy T with an angle θ whereas the photon will scatter with energy E’ and angle θ [2-4]. The energy of scattered photon can be calculated using Compton relationship:

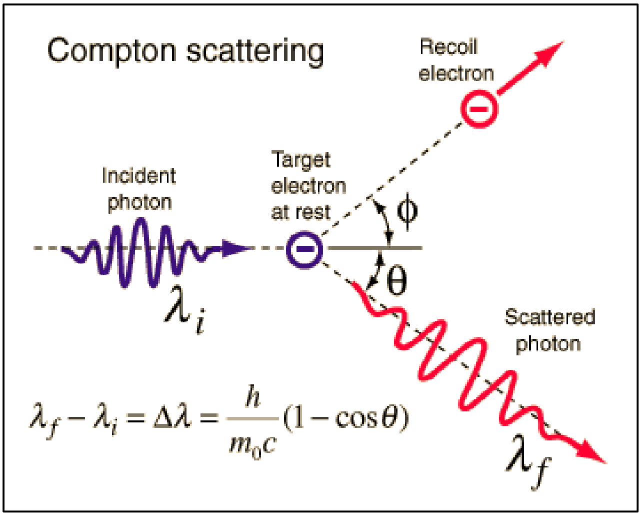

Figure 1.
Description of Compton scattering [4].

$$E_\gamma' = \frac{E_\gamma}{\left(1+[(E_\gamma/m_0c^2)(1-\cos\theta)]\right)} \qquad 1$$

When using a ^{137}Cs source with photon energy of 0.662 MeV, and knowing that m_0c=0.511MeV, then the formula for single Compton scattered events may be rewritten as:

$$E_\gamma' = \frac{0.662}{\left(1+[(0.662/0.511)(1-\cos\theta)]\right)};$$

$$E_\gamma' = \frac{1}{(1.51+1.956(1-\cos\theta))}$$

By taking reciprocals, this becomes:

$$\frac{1}{E_\gamma'} = 1.51+1.956(1-\cos\theta) \qquad 2$$

2.3 Pair Production

In this interaction the electric field near the protons in the nuclei and the positron pair produced in for this type of exceeds 1.02 MeV ($m_o c^2$=2×0.511=1.022 MeV) [3-4].

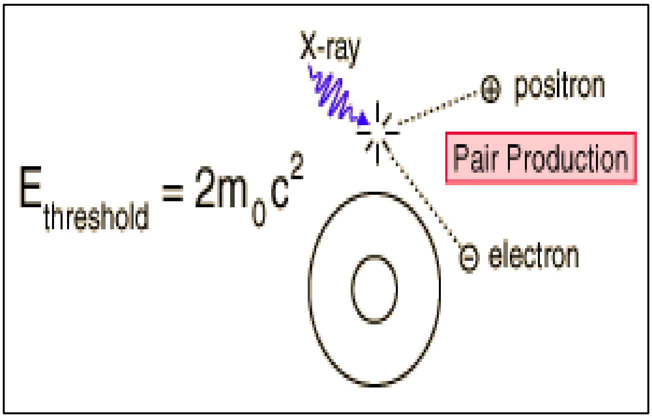

Figure 2: describe pair production [5].

The attenuation of gamma-rays can be reduced in intensity only by increasing the thickness of the absorber and may not completely absorb according to Beer's low:

$$I = I_0 e^{-\mu x} \quad \text{or} \quad (I / I_0) = e^{-\mu x}$$

$$\ln\left(\frac{I}{I_o}\right) = -\mu x \qquad 3$$

Where; I is transmitted photon intensity, I_0, incident photon intensity, μ, liner attenuation coefficient and x = thickness of absorbing material.

The Klein Nishina equation describes the differential scattering cross section, $\left(\frac{d\delta}{d\Omega}\right)$.

$$\frac{d\delta}{d\Omega} = \frac{r^2{}_0}{2\{((1+\cos^2\theta)/(1+a(1-\cos\theta))^2\}}$$

$$\frac{d\delta}{d\Omega} = \frac{r^2{}_0}{2\{((1+\cos^2\theta)/(1+a(1-\cos\theta))^2\}\times\{1+[a^2(1-\cos\theta)^2/(1-\cos^2\theta)(1+a(1-\cos\theta))]\}} \quad \text{.........4}$$

Where $\left(\frac{d\delta}{d\Omega}\right)$ is the probability that a photon will scatter in a small solid angle dΩ and it has units, m^2/Sr and r_0 is the classical electron radius, which equal to $2.82\times10^{-}m^{15}$;

$$a = \frac{Ey}{m_oc^2} = \frac{0.662}{0.511} = 1.2955$$

For ^{137}Cs which is the source used in the experiment. θ is the detector angle with respect to the source direction, so it is the scattering angle. Finally, the results which obtained from Klein-Nishina equation can be compared with the experimentally results which can be obtained from this expression that take the source activity, type of scattering, geometry and detector efficiency into account.

$$\frac{d\delta}{d\Omega} = \frac{\sum y}{K\Delta\Omega I} \quad 5$$

Where, Σγ is sum under the full energy peak divided by the intrinsic peak efficiency per unit time. K is the number of electrons the scattering sample and it is defined as:

$$K = \frac{V\times\rho\times A\times N_A}{M} \quad 6$$

Where: (V) is a volume, (ρ) is a density, (A) is an atomic number, N_A an Avogadro's number and (M) is a atomic weight.

$$\Delta\Omega = \frac{A_d}{d^2}$$ 7

ΔΩ is a solid angle of the detector in steradians, and A_d is a detector surface area and d is the distance from scatter to detector face [3-5].

$$I = \frac{\text{Activity of the source (Bq)}}{4\pi R^2}$$

8

Where: I is flux of γ-rays incident on the sample (photons/m^2s), and R is the distance from the source to center of sample.

3. Experimental Apparatus and Procedure

3.1 Photon Attenuation

Experiment equipment

This part of the experiment was setup by using HpGe detector, which connected to a preamplifier, then shaping amplifier that connected amulet channel analyser (MCA) to calibrate ^{152}Eu source with lifetime 200s.

Experiment method

At the beginning, the ^{152}Eu source was placed in front of the detector with the count time 200s, over the energy rang 121 keV to 1408 keV. The spectrum was collected for the ^{152}Eu source, and the spectrum peaks were measured for seven ROI`S which formed as a result of various gamma have the following energies, 121, 244, 344, 778, 964, 1112 and 1408 keV of absorber, the amount of lead absorbers between the detector and the sources from 0.6

g/cm^2 up to 35 g/cm^2. The intensity of each γ-rays energy peaks decrease at different rates with absorber thickness intensity is related to an absorber thickness by $I=I_0e^{-\mu X}$, Where I is a net count with absorber, I_0 is a net counts with no absorber, x is a mass thickness and μ being the mass attenuation coefficient. After that data have been collected, the graphs were plotted for the thicknesses against ln (I/I_0), and consequently the mass attenuation coefficients were calculated, and the graph was plotted from the calculated mass attenuation coefficient for each peak against the energy of each peak.

3.2 Scattering Energy

Experiment equipments

Gamma-rays scattering and attenuation of gamma-rays was studied by using a Nal (TL) scintillation crystal spectrometer by using a ^{137}Cs source with photon energy of 662 keV. A source was placing into plastic vial then placing the vial into aluminum at centre of rotation of the Compton scattering in the right angles, the spectrum was recorded; then replace the ^{137}Cs source with a ^{133}Ba source.

Experiment method

In this part of the experiment by located the detector is at right angles to the collimator, by placing a ^{137}Cs source into the plastic vial provided, and place the vial onto the aluminum the center of rotation then replace the ^{137}Cs source with a ^{133}Ba source, the new spectrum was recorded over the ^{137}Cs spectrum. In addition, the peaks of ^{133}Ba have these gamma ray energies 80.99kev and 356.01 keV, with the ^{137}Cs peak 661.64 keV was calibrated by using MCA. The second step was placed the 2.5 cm diameter aluminum rod on the center of rotation and rotate the detector to an angle of 200 and the energy spectrum was collected for preset time of 300s. The spectrum was collected contains the Compton scattered signal from the aluminum rod unwanted radiation scattered into the detector from the bench and another locations. Thus by removing the aluminum rod from its position at the centre of radiation and copying the spectrum to buffer. This keeps the data in memory while allowing a new spectrum to be captured, which has a signal unwanted scattered radiation from the bench and other locations by subtracting this second spectrum from the original in the buffer. Therefore, the final spectrum is collected of the radiation Compton scattered from the aluminum rod. The peak centroid energy and count rate were recorded. Repeat these measured for angles 400, 600, 800 and 1000 and for the same time in each case, the data was collected to represents the measured **E'γ** against different angles where the centroid represents **E'γ** experimentally. The **E'γ** was calculated using equation (1) given above. Then a graph was plotted for both measured and calculated **E'γ** against every angle, and then by using equation (2), a graph was plotted of $\left(\frac{1}{E'\gamma}\right)$ versus $(1-\cos\theta)$.

3.3 Differential Scattering Cross Section

The results in the previous from the second part of this experiment were used in equation (5) to find $\left(\frac{d\delta}{d\Omega}\right)$ experimentally for several values of θ in the range 200 to 1000. The graph of $\left(\frac{d\delta}{d\Omega}\right)$ versus the scattering angles θ was plotted by using the Klein-Nishina equation to calculation the $\left(\frac{d\delta}{d\Omega}\right)$. The result was plotted in the same graph to compare between the experimental measurements and theoretical calculations.

Result and Discussion

A. Photon Attenuation

This section of experiment is divided into parts where the ^{152}Eu source was used. In the first part, the calibration of the detector was preformed with a ^{152}Eu spectrum were identified and their energies assigned to channel number. The peaks were chosen to span a wide gamma energy range, 121, 244, 344, 778, 964, 1112 and 1408 keV. The Figures 3 to 9 and tables 1-10 below show the data concerning each peak of ^{152}Eu source. The second requirement in this experiment by placing thickness of absorber on top of the source was investigated to determine whether an increased scattered in component could be detected; the position of source on the layers of concrete was investigated. Then from equation (3) the graph of the thickness versus ln (I/I_0) was done. The mass attenuation coefficient was obtained, μ was investigated to determine of seven full energy peaks were chosen throughout the spectrum for investigation then the linear coefficient attenuation varies with the peaks energies as shown in Figure 10. Figures 1-9 show the mass attenuation coefficients of all energies, 121, 244, 344, 778, 964, 1112 and 1408 keV, respectively.

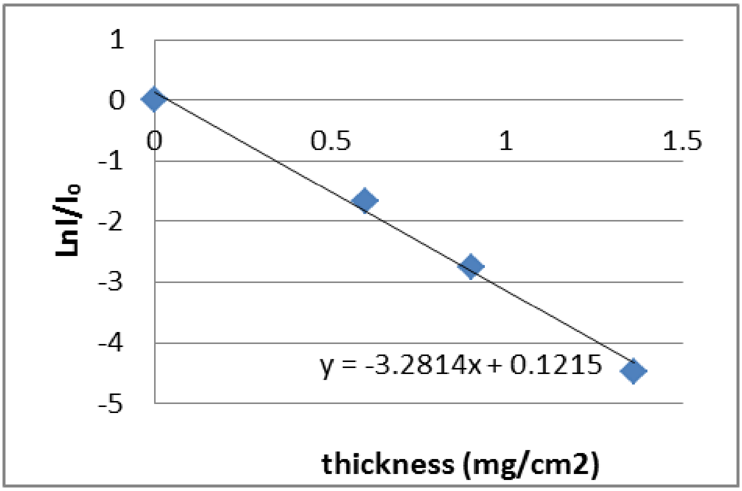

Figure 3. Shows the data concerning each peak of ^{152}Eu (121kev).

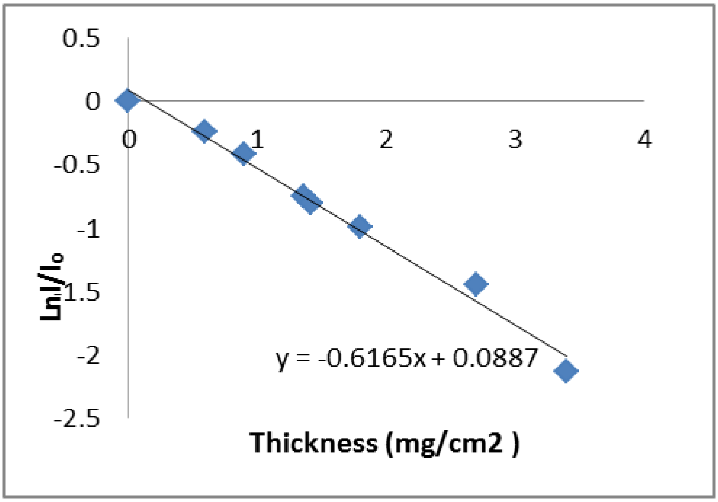

Figure 4. Shows the data concerning each peak of ^{152}Eu (244kev).

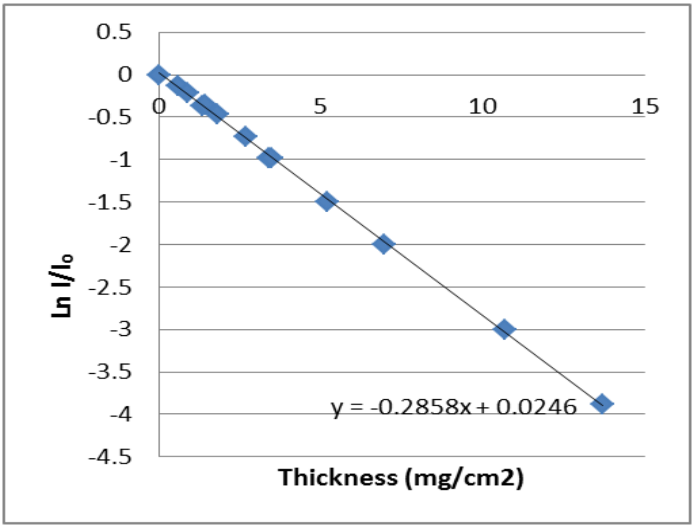

Figure 5. Show the data concerning each peak of ^{152}Eu (344kev).

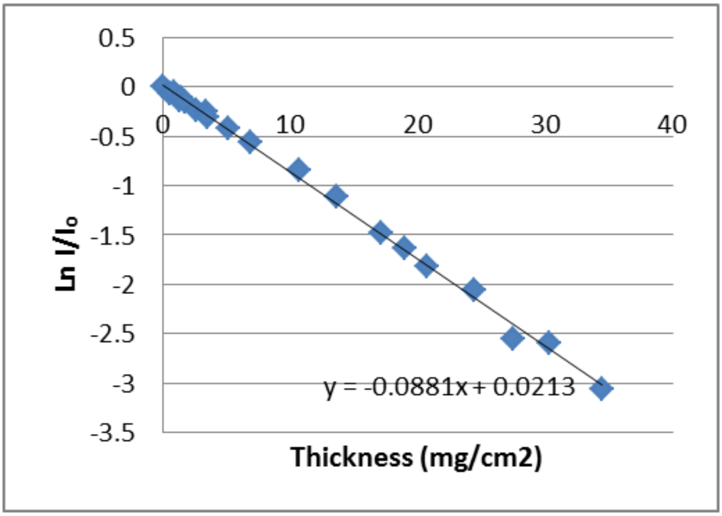

Figure 6. Shows the data concerning each peak of ^{152}Eu (778kev).

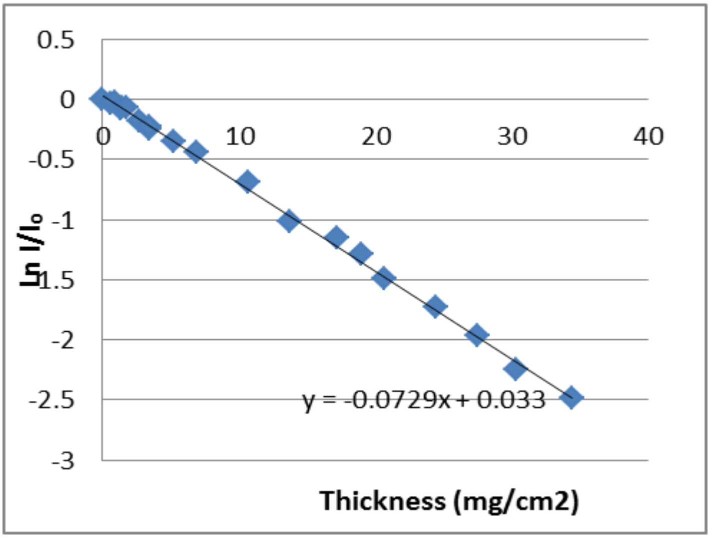

Figure 7. Shows the data concerning each peak of ^{152}Eu (964kev).

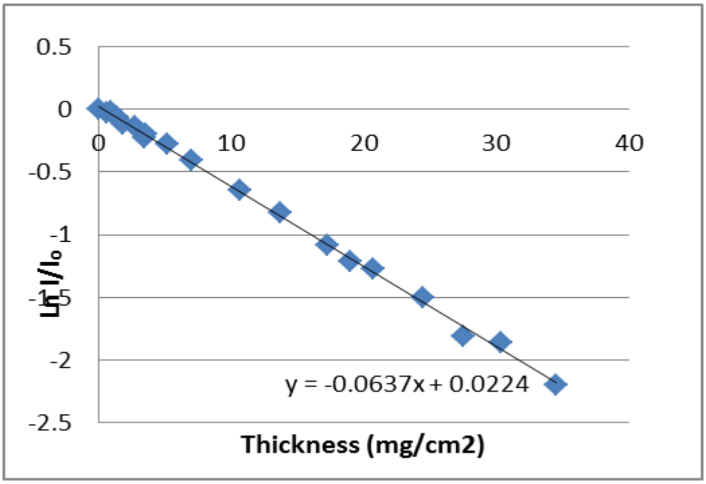

Figure 8. Shows the data concerning each peak of ^{152}Eu (1112kev).

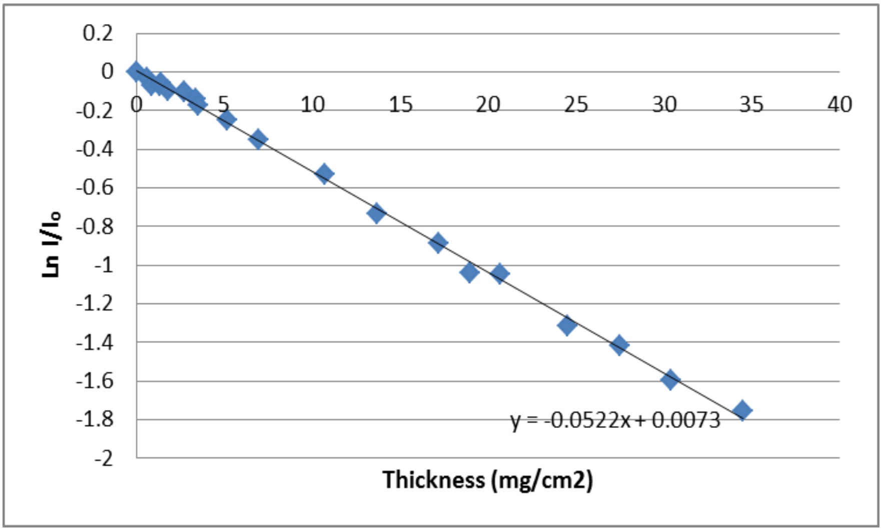

Figure 9. Show the data concerning each peak of ^{152}Eu (1408kev).

Figure 10 below shows the linear mass attenuation confirms that the energy of gamma rays was decrease quickly at the beginning, then decrease slowly between 244 and 800 keV.

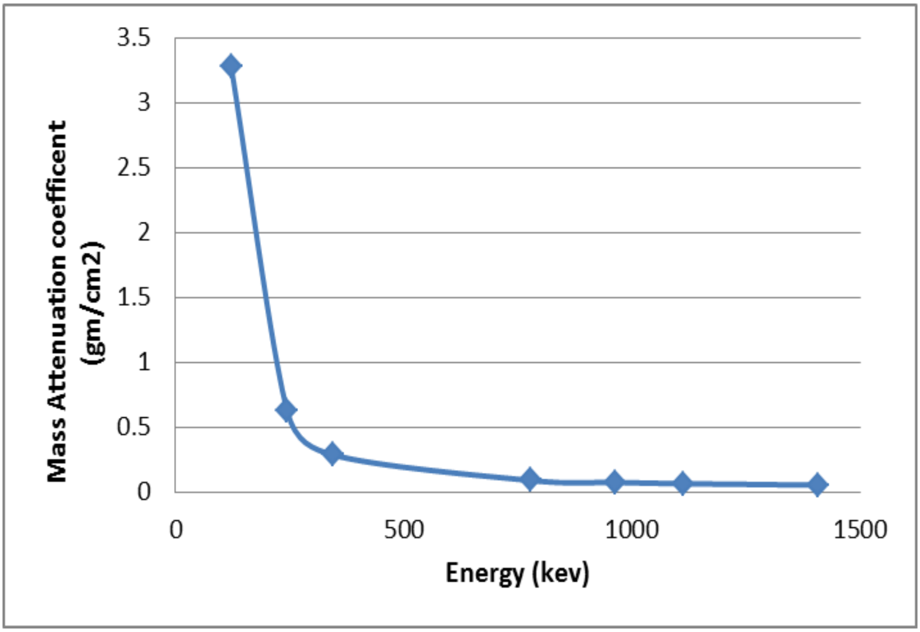

Figure 10. Mass attenuation coefficient vs Energy

B. Scattering Energy

The Compton scattering shows in Figure (11), it was found that the energy of the scattering rays decrease as the angle of scattering increasing. It can be noticed two values of scattered photon energy (E'γ) of experimental measurement and theoretical calculations from using equation (1). It can be found from the figure that the measurements and calculations data are nearly similar with little difference in some points. When the interaction of photon with the matter electrons, the photon lost part of the energy, the fraction of incident photon energy the deal of this fraction concerning on the angle.

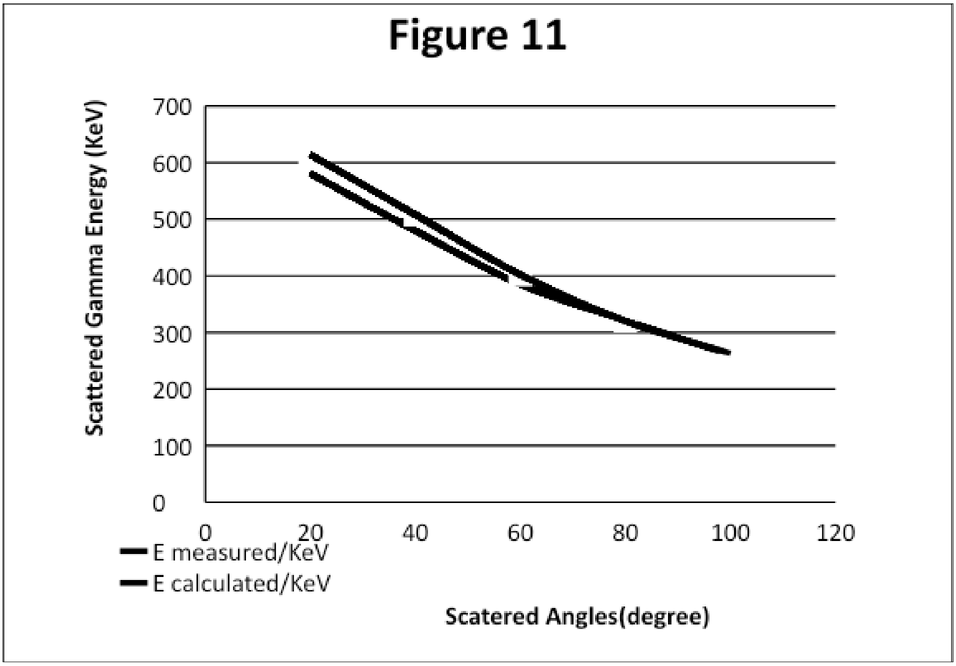

Figure 11. The energy of the scattering rays decrease as the angle of scattering increasing

Figure 12 shows the relationship between 1/E'γ versus (1-cosθ), from the graph of 1/E'γ versus (1-cosθ), the result in a straight line with intercept 1.5114 and gradient 1.9522. The result from both measured and calculated data by using equation (2). This result is quiet similar to the theoretical values where the intercept is 1.51 and the gradient is 1.956.

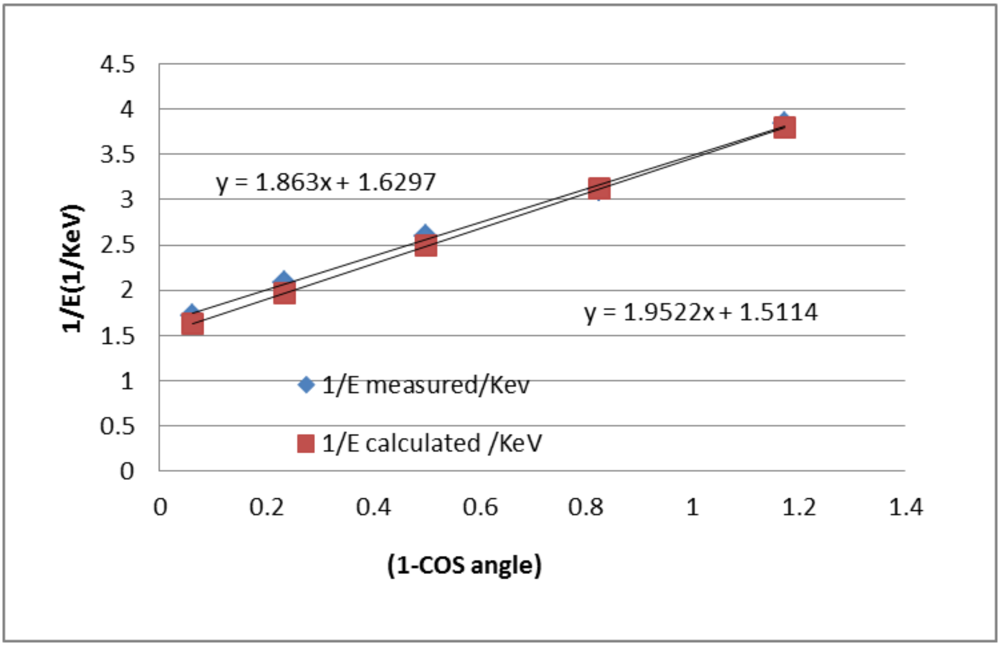

Figure 12. The relationship between 1/E'γ versus (1-cosθ).

C. Differential Scattering Cross Section

By using the Klein-Nishina equation mentioned above equation (4) to calculate the dδ/dΩ for photon scattering from electrons, for several values of θ in the range 200 to 1000, taking into account the following calculations:

K = (volume* density* atomic number* Avogadro number)/ atomic weight

The aluminium rode volume = 3.93x 10^{-5} m^3.

Aluminium density =2.7 x 10^6 g/m^3.

Atomic number= 13

Avogadro number = 6.022 x 10^{23} atoms/mole

Atomic weight = 26.98 g/ mole

K= (3.93x 10^{-5}* 2.7 x 10^6 * 13* 6.022 x 10^{23} *)/26.98

K=3.079 x 10^{25} electrons.

$\Delta\Omega=A/d^2$

Where A is detector surface area, which was found to be 5.63x 10^{-3} m^2 and d is the distance from scatterer to detector face, which is 0.2m.

$\Delta\Omega= 5.63x\ 10^{-3}/0.2^2$

$\Delta\Omega$=0.14075 sr

I = (Activity of the source (Bq))/ $4\pi R^2$

Activity of the source at the day of experiment=257.583kBq.

Where, R is the distance from the source to centre of sample, which is 0.345m.

I=1.72 X10^5 Bqm^{-2}.

$\sum\gamma' = N\gamma\ /\varepsilon P\ t$

Where, Nɣ the count under the peak and εP the intrinsic efficiency and t is the time taken to collect these counts. It found εP 0.006 and t =300s.

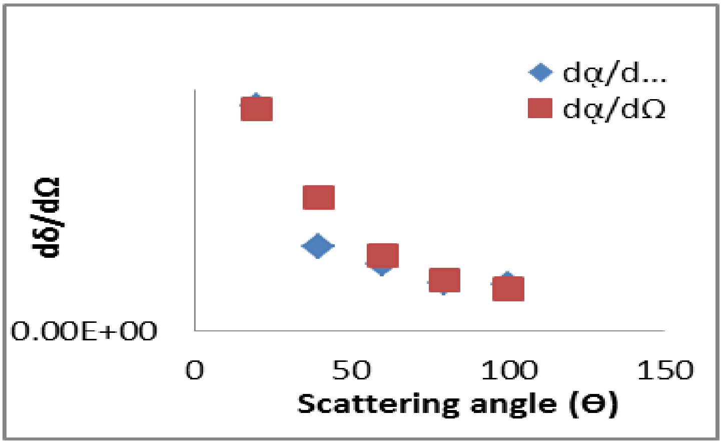

Figure 13. Differetial scattering cross section.

From Figure 13 it can be noticed that the measured and calculated values were differential cross section for Compton scattering. It can be seen from the figure the calculated and measured data have the same direction. The possibility of interaction between the photon and electron decreases with increasing the angle.

Table 1. The data concerning peak of ^{152}Eu source Energy 121keV

Thickness (gm/cm^2)	Net counts I	ln I/I$_0$
0	58583	0
0.6	10950	-1.67711
0.9	3731	-2.75377
1.36	672	-4.46794

Table 2. The concerning peak of Energy 244 keV.

Thickness (gm/cm^2)	Net counts I	ln I/I$_0$
0	10085	0
0.6	7907	-0.2433
0.9	6598	-0.42428
1.36	4773	-0.74807

1.42	4477	-0.8121
1.8	3748	-0.98983
2.7	2364	-1.45069
3.40	1197	-2.13123
3.5	1218	-2.11384

Table 3. The concerning peak of Energy 344 keV.

Thickness (gm/cm^2)	Net counts I	ln I/I_0
0	25546	0
0.6	22387	-0.1320003
0.9	20562	-0.217036
1.36	17634	-0.3706519
1.42	17965	-0.3520553
1.8	16073	-0.4633399
2.7	12361	-0.7259344
3.40	9595	-0.9792386
3.5	9558	-0.9831022
5.2	5706	-1.4989625
6.95	3449	-2.0023964
10.7	1275	-2.9975346
13.7	524	-3.8867443

Table 4. The concerning peak of Energy 778 keV.

Thickness (gm/cm^2)	Net counts I	ln I/I_0
0	5638	
0.6	5294	-0.06296
0.9	5334	-0.05543
1.36	4911	-0.13805
1.42	5030	-0.11411
1.8	4860	-0.14849
2.7	4431	-0.2409
3.5	4144	-0.30787
5.2	3684	-0.42553
6.95	3213	-0.56232
10.7	2412	-0.84907
13.7	1844	-1.11759
17.2	1283	-1.48033

19	1093	-1.6406
20.7	911	-1.82274
24.5	3932	-2.0636
27.5	441	-2.54824
30.38	421	-2.59465
34.5	263	-3.06513

Table 5. The concerning peak of energy 1112 keV.

Thickness (gm/cm^2)	Net counts I	ln I/I_0
0	4222	0
0.6	4091	-0.03152
0.9	4147	-0.01792
1.36	3983	-0.05827
1.42	3943	-0.06837
1.8	3745	-0.11989
2.7	3675	-0.13876
3.5	3471	-0.19587
5.2	3202	-0.27653
6.95	2817	-0.40464
10.7	2208	-0.64822
13.7	1851	-0.82458
17.2	1434	-1.07984
19	1250	-1.21717
20.7	1187	-1.26888
24.5	937	-1.50538
27.5	691	-1.80992
30.38	656	-1.8619
34.5	467	-2.20173

Table 6. The concerning peak of Energy 1408 keV.

Thickness (gm/cm^2)	Net counts I	ln I/I_0
0	5224	
0.6	5044	-0.03506
0.9	4871	-0.06996
1.36	4874	-0.06935
1.42	4930	-0.05792
1.8	4745	-0.09617
2.7	4709	-0.10379

3.40	4541	-0.14012
3.5	4408	-0.16984
5.2	4066	-0.2506
6.95	3686	-0.34872
10.7	3079	-0.52866
13.7	2506	-0.73458
17.2	2150	-0.8878
19ل	1842	-1.04241
20.7	1836	-1.04567
24.5	1405	-1.31323
27.5	1263	-1.41977
30.38	1061	-1.59405
34.5	904	-1.75419

Table 7. The angle with the measured energy and the calculated energy.

Angle	E, keV	
	Measured	Calculated
20	580.84	614
40	479.67	508
60	385.14	402
80	321.11	320
100	260.61	263

Table 8. $(1-\cos\theta)$ with 1/E for both the measured and calculated energies.

$(1-\cos\theta)$	1/E MeV	
	Measured	calculated
0.06030738	1.721645	1.628664495
0.23395556	2.084767	1.968503937
0.5	2.596458	2.487562189
0.82635182	3.114198	3.125
1.17364818	3.837151	3.802281369

Table 9. Calculated dδ/dΩ

Angle (degree)	dδ/dΩ calculated
20	6.45E-30
40	3.87E-30
60	2.19E-30
80	1.47E-30
100	1.20E-30

Table 10. Measured dδ/dΩ

Angle (degree)	∑ɣ =N ɣ /εp t	dδ/dΩ measured (m^2/sr)
20	6.7	6.52E-30
40	4.980556	2.42E-30
60	3.963889	1.93E-30
80	2.861111	1.39E-30
100	2.725	1.33E-30

Conclusions

The general features of gamma rays scattering and attenuation have investigated, the photon attenuation, scattering of gamma photons and differential scattering cross section were studied. The experimental results show that the calibration of HpGe detector was performed with a ^{151}Eu source; it was found seven clear full energy peaks of ^{151}Eu to span a wide gamma rays energy range, 121, 244, 344, 778, 964, 1112 and 1408 keV. The position of the source on the layers of aluminum has been investigated, the effect of several interaction of gamma rays, when passing through on variety thickness. It was found that the absorber thickness is an important strongly affects the intensity of gamma ray. Moreover, it noticed from the experimental results that the linearity of intensity of gamma ray, and absorber thickness was identified from Beer’s law. In addition, the linear mass attenuation coefficient varies with energy peak; it was found the mass attenuation coefficient decreases sharply at the beginning, then decreases slowly in the energy 244, 800 keV. It can be observed clearly from Figure 8 is more significant at law energies, in comparison with high energies. The behaviors of Compton scattering interaction was studied, Figure 9 shows the change in the energy of scattered gamma photons (E’ɤ) with the increasing in the scattering angle value. Figure 10 illustrates the relationship between 1/E’ɤ and (1-cosθ) the result in a straight line with intercept 1.594 and gradient 1.9667, whereas the theoretical values are 1.956 and 1.51 respectively. Finally, this experiment was carried out differential cross section using the Klein-Nishina equation. The interaction between the photon and the electron decreases with increasing the scattering angle, also the results were obtained experimentally were found to be good agreement with theoretical values and similar result found by Eftekhari *et al*. [6].

5. References

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