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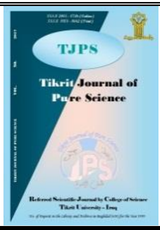

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# Mass Attenuation Coefficient Measurements of Photoelectric Absorption of Gamma-Rays in Copper Using Coincidence Technique

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## ABSTRACT

The photoelectric absorption mass attenuation coefficients (m.a.c.) of ɤ- rays in Cu are measured using a two 3"x3" NaI(Tl) detector coincidence spectrometer at 511, 1173 and 1332keV energy gates using Na-22 and Co-60 point sources. The m.a.c. (in cm²/g) measured by coincidence method were lower than those obtained from direct measurement. Coincidence measurements revealed the coefficients 0.0429, 0.0212 and 0.0205 and direct measurements the coefficients 0.0561, 0.0239 and 0.0220 for the studied energies respectively. The µm (co) /µm (dir) ratios were 0.763, 0.8900 and 0.9345at the three energies mentioned respectively. The coincidence coefficients also behave as those of direct spectra as with change in energy.

## 1- Introduction

Although the physics of the interactions of gamma-rays with matter by the three main processes, namely photoelectric effect, Compton scattering and pair production is well-known, there still some difficulties and complexity that arise in the accumulation and treatment of data registered by ɤ-ray detectors. For instance, the poor energy resolution limits the operation and achievement of scintillation detectors although these possess excellent timing characteristics. On the other hand the superior energy resolution ability obtained by using ɤ-ray semiconductor detectors is accompanied by some disadvantages in timing response of these detectors that may not match the resolution ability [1,2].

For both the mentioned categories of ɤ-ray detectors, common difficulties are opposed when making measurements of certain experiments. The familiar measurement of ɤ -ray attenuation requires that in order to use the well-known Lambert equation I= I0 $e^{-\mu t}$ (where I0 and I are the beam intensities both initially and at thickness $t$ respectively and µ is the attenuation coefficient) the beam should be monoenergetic and well collimated [2].

However, most actual measurements are not such alike, and beams are spread and allowed to penetrate through different thicknesses of absorbing materials. This results, and in particular with intense beams, in the broadening and distortion of the obtained photopeaks. Trials were made to correct these through build - up factor corrections made both experimentally and theoretically [2].

Further insight on solving the problem of peak broadening in attenuation experiments may be suggested through the use of coincidence technique. Here the advantage is through the ability of obtaining only isolated photopeaks of the spectrum of penetrated ɤ-ray through elimination of other phenomena like Compton distribution and background, by careful adjustment of the two–detector spectrometer [1].

Recently several researches had concentrated on using the coincidence technique in the investigation of ɤ-ray attenuation through materials. Results revealed that the obtained attenuation coefficients registered by using the coincidence method were lower than those by direct measurements [3], either by using different forms of materials [4] or different energies [5] or even build-up factors by using coincidence method [6]. In this study we investigate the attenuation in copper material by using the coincidence method aiming at the confirmation of the previous results as well as enhancing the application of the coincidence technique in attenuation measurements.

## 2- Theory

In attenuation measurement of ɤ-rays and in most the cases where a large fraction of scattered and secondary photons reach the detector, the attenuation in this case becomes greater than the case of arrival of little fraction of scattered and secondary photons to the detector due to the collimation of the beam by a collimator that reduces the scattered photons. In this case the attenuation of uncollimated beam becomes larger than that of the collimated beam. The Lambert equation is valid when using collimated beam, but when using uncollimated or wide beam, a build-up factor correction is introduced. The build-up factor results from two main causes, Compton scattering and pair production [2].

Attenuation coefficient depends upon material type and ɤ-ray energy, and for the cases of including more than one energy in the beam their intensities are calculated separately.

The inspection of the photopeak due to the transmitted ɤ-ray shows that the peak includes a part of unattenuated photon energy in addition to the possibility of attenuated photon energy. The complexity and interference of energy and intensity may make a confusion and difficulties in calculations when differentiating between the behavior of ɤ- ray in air and that in the absorbing material. The attenuation in intensity may also be accompanied by an attenuation of the ɤ-ray energy itself and a broadening of the resultant photopeak.

In this study we use the coincidence technique to investigate the transmitted and not attenuated in energy beam, through imposing the coincidence criteria in timing and energy.

## 3- Apparatus

In this research a fast / slow ɤ- ɤ coincidence spectrometer composed of two 3"x3" NaI(Tl) detectors with the required electronics as shown in Fig. (1) is used. Two ɤ-rays point sources are used, namely Na-22(0.4 μCi) and Co-60 (0.5μCi). Copper sheets with dimensions 8x8 $cm^2$ are used. The measurements were carried out at department of physics, college of education, university of Baghdad.

An energy gate is selected in one of the spectrometer branches, the other branch allows the whole spectrum pulses to pass and the studied thickness of material is placed between the source and detector of this branch. The measurements include registering the direct spectrum followed by the coincidence spectrum. Three energy gates are selected here, 511keV (for Na-22 source) and 1173 and 1332keV (for Co-60 source).

The mass attenuation coefficient is obtained by using the Lambert relation for both direct and coincidence spectra for the selected gates. In the following we present the results of these measurements.

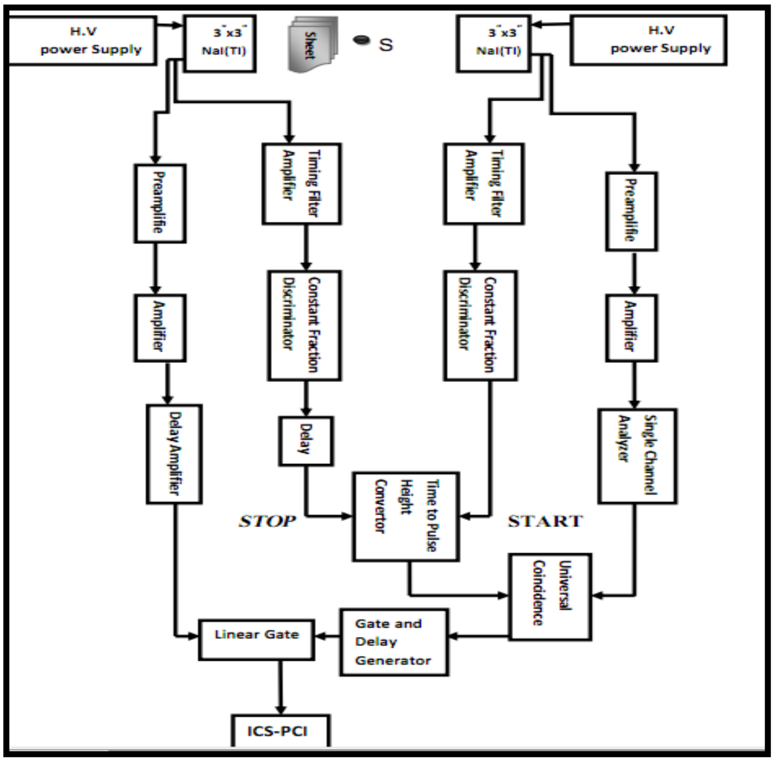


**Fig. 1: Block diagram of the gamma-gamma coincidence spectrometer**

## 4- Measurements and Results

### I- Gate 511keV:

### a- direct spectrum

The measurements were carried out using Na-22 source and Cu sheets. The results are presented in Table (1). Net peak areas NPA refer to the intensities of the transmitted ɤ- photons I. Aplot of (ln I) against thickness T is shown in Fig (2). The linear attenuation coefficient (l.a.c.) obtained here is μ= 0.5035 $cm^{-1}$. The mass attenuation coefficient (m.a.c.) is μm=

0.0561 cm²/g at E=511keV. The nearest calculated energy in standard tables at E=500keV gives $\mu_m$= 0.0822 cm²/g [7], keeping in mind that this is for the three interaction processes and our calculations are for the photo electric interaction only.

**Table 1: photopeak data for direct measurements of Cu at the 511keV gate.**

| Spectrum | Thickness (cm) | Centroid (ch) | FWHM | NPA | Ln I |
|---|---|---|---|---|---|
| DS | 1.3 | 66.89 | 6.89 | 11854 | 9.380 |
| DS | 1.95 | 66.37 | 6.73 | 7978 | 8.984 |
| DS | 2.6 | 66.75 | 6.81 | 5570 | 8.625 |
| DS | 3.9 | 66.74 | 6.52 | 2146 | 7.671 |
| DS | 5.2 | 66.45 | 6.95 | 1288 | 7.160 |
| DS | 6.5 | 66.07 | 6.46 | 674 | 6.513 |
| DS | 7.8 | 66.85 | 6.96 | 504 | 6.222 |

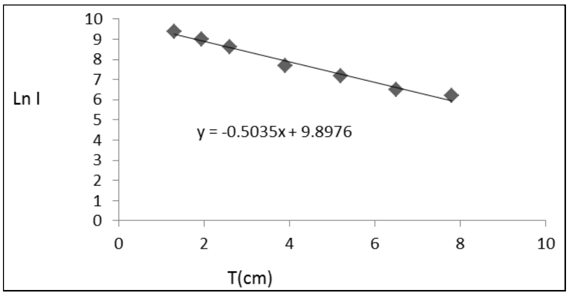


**Fig. 2: Relationship between thickness T(cm) and Ln I for direct measurements of Cu at the 511keV gate.**

### b- Coincidence spectrum

Using the 511keV gate, the coincidence spectra are obtained at different thicknesses and data are presented in Table (2). The l.a.c. as calculated from the plot of Fig.(3) is μ = 0.3846 cm⁻¹ and μm = 0.04292 cm²/g.

**Table 2: photopeak data for coincidence measurements of Cu at the 511 keV gate.**

| Spectrum | Thickness (cm) | Centroid (ch) | FWHM | NPA | GROSS AREA | Ln Gross |
|---|---|---|---|---|---|---|
| CS | 1.3 | 68.35 | 7.08 | 10542 | 11262 | 9.329 |
| CS | 1.95 | 67.93 | 7.06 | 7428 | 7961 | 8.982 |
| CS | 2.6 | 68.31 | 6.92 | 5156 | 5602 | 8.630 |
| CS | 3.9 | 68.36 | 6.51 | 5214 | 2792 | 7.934 |
| CS | 5.2 | 67.76 | 6.73 | 1889 | 2134 | 7.665 |
| CS | 6.5 | 67.93 | 6.41 | 1341 | 1578 | 7.363 |
| CS | 7.8 | 67.86 | 6.70 | 671 | 794 | 6.677 |

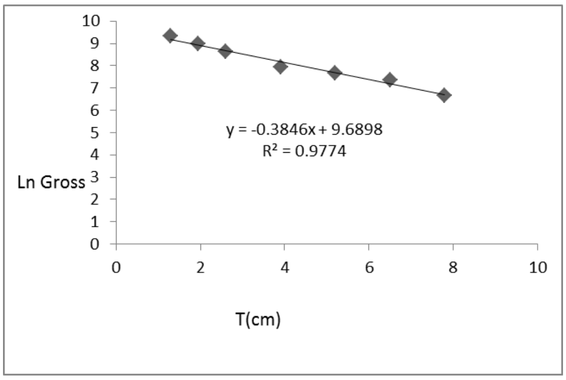


**Fig. 3: Relationship between thickness T (cm) and Ln Gross for coincidence measurements of Cu at the 511keV gate.**

## II - Gate 1332keV

### a- direct spectrum

The Co-60 source is used in making the measurements of direct spectrum for the 1173keV energy which is in time coincidence with the 1332keV line. Table (3) presents the data collected for the different thicknesses. Fig. (4) shows that the l.a.c calculated is μ=0.2143 $cm^{-1}$ and the corresponding m.a.c is $\mu_m$= 0.02391 cm²/g at E= 1173keV.

**Table 3: photopeak data for direct measurements of Cu at the 1332keV gate.**

| Spectrum | Thickness (cm) | Centroid (ch) | FWHM | NPA | Ln I |
|---|---|---|---|---|---|
| DS | 1.3 | 91.30 | 8.15 | 6023 | 8.704 |
| DS | 1.95 | 91.27 | 8.13 | 5158 | 8.548 |
| DS | 2.6 | 91.35 | 8.44 | 4295 | 8.365 |
| DS | 3.9 | 91.64 | 7.91 | 2711 | 7.905 |
| DS | 5.2 | 91.74 | 8.47 | 2327 | 7.752 |
| DS | 6.5 | 91.86 | 8.67 | 1988 | 7.594 |
| DS | 7.8 | 91.89 | 8.69 | 1461 | 7.286 |

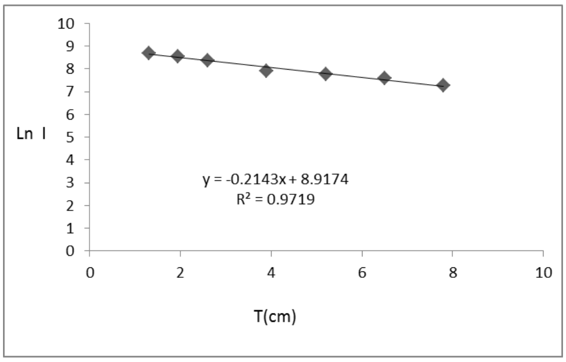


**Fig. 4: Relationship between thickness T(cm) and Ln I for direct measurements of Cu at the 1332keV gate.**

**b – coincidence spectrum**

When using the 1332keV gate, only the 1173keV line of Co-60 source appeared in the spectrum shown in Fig. (5). The data for the different thicknesses is presented in Table (4). Fig. (6) shows that the l.a.c calculated from these data is μ=0.1907 $cm^{-1}$ *and* $\mu_m$= 0.0212 cm²/g .

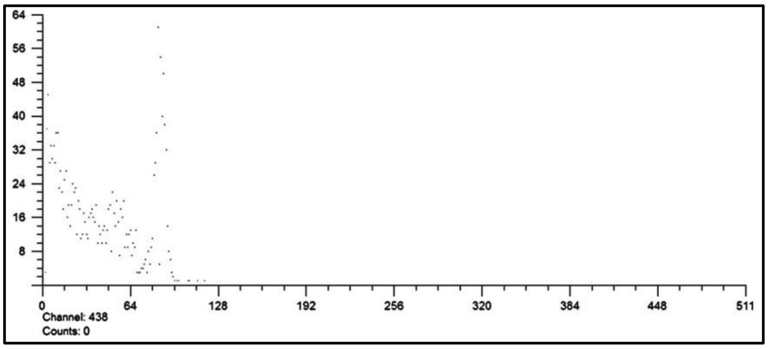


**Fig. 5: coincidence Spectrum at the 1332KeV gate.**

**Table 4: photopeak data for coincidence measurements of Cu at the 1332keV gate.**

| Spectrum | Thickness (cm) | Centroid (ch) | FWHM | NPA | Gross | Ln Gross |
|---|---|---|---|---|---|---|
| CS | 1.3 | 85.51 | 8.57 | 667 | 724 | 6.584 |
| CS | 1.95 | 85.75 | 7.61 | 486 | 587 | 6.375 |
| CS | 2.6 | 85.65 | 8.82 | 449 | 506 | 6.226 |
| CS | 3.9 | 85.49 | 6.60 | 241 | 326 | 5.786 |
| CS | 5.2 | 86.74 | 7.50 | 199 | 337 | 5.820 |
| CS | 6.5 | 85.63 | 7.35 | 213 | 260 | 5.560 |
| CS | 7.8 | 86.37 | 7.47 | 132 | 190 | 5.247 |

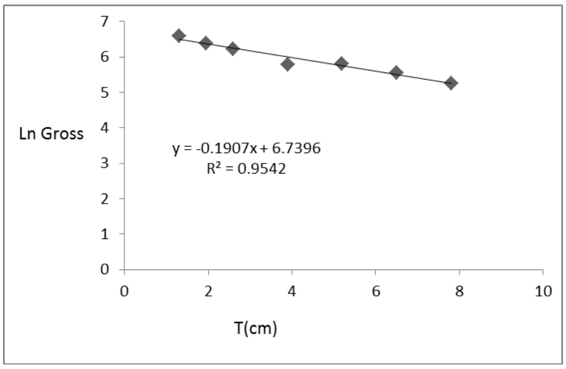


**Fig. 6: Relationship between thickness T(cm) and Ln Gross for coincidence measurements of Cu at the 1332keV gate.**

**III – Gate 1173keV**

**a- direct spectrum**

The data collected for the 1332keV line which is in time coincidence with the 1173 keV line is presented in Table (5) .Fig. (7) shows that the l.a.c. calculated from these data is μ=0.1972 $cm^{-1}$ *and* $\mu_m$= 0.0220 cm²/ g.

**Table 5: photopeak data for direct measurements of Cu for the 1173keV gate.**

| Spectrum | Thickness (cm) | Centroid (ch) | FWHM | NPA | Ln I |
|---|---|---|---|---|---|
| DS | 1.3 | 108.35 | 6.99 | 4882 | 8.493 |
| DS | 1.95 | 108.29 | 7.21 | 4210 | 8.323 |
| DS | 2.6 | 109.09 | 7.51 | 3538 | 8.171 |
| DS | 3.9 | 109.43 | 7.18 | 2618 | 7.870 |
| DS | 5.2 | 108.79 | 7.14 | 2122 | 7.660 |
| DS | 6.5 | 109.53 | 6.96 | 1838 | 7.516 |
| DS | 7.8 | 108.97 | 6.78 | 1256 | 7.135 |

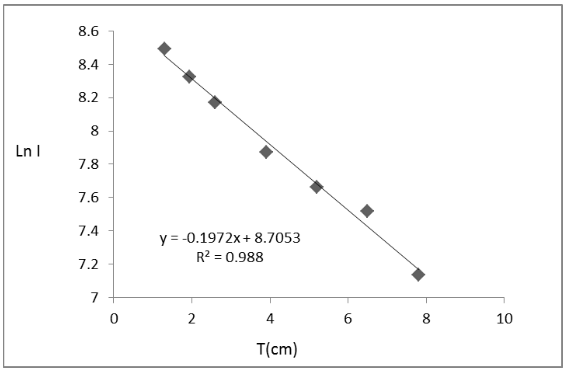


**Fig. 7: Relationship between thickness T(cm) and Ln I for direct measurements of Cu at the 1173keV gate.**

**b- Coincidence spectrum**

Fig. (8) Presents a coincidence spectrum of this gate. The data of these measurements for different thicknesses are presented in Table (6). Fig. (9) shows that the l.a.c. calculated from the data is μ=0.1843 $cm^{-1}$ and $\mu_m$= 0.0205 cm²/g.

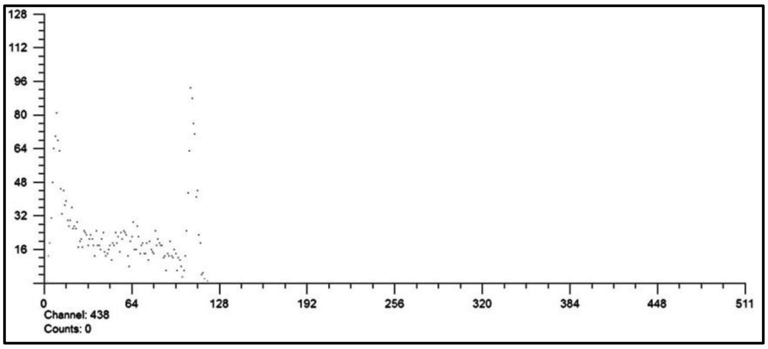


**Fig. 8: coincidence Spectrum at the 1173KeV gate.**

**Table 6 : photopeak data for coincidence measurements of Cu at the 1173keV gate.**

| Spectrum | Thickness (cm) | Centroid (ch) | FWHM | NPA | GROSS AREA | Ln Gross |
|---|---|---|---|---|---|---|
| CS | 1.3 | 108.77 | 7.42 | 679 | 757 | 6.629 |
| CS | 1.95 | 108.03 | 6.65 | 653 | 620 | 6.429 |
| CS | 2.6 | 109.06 | 7.20 | 423 | 538 | 6.287 |
| CS | 3.9 | 109.06 | 6.17 | 314 | 400 | 5.991 |
| CS | 5.2 | 108.92 | 7.80 | 287 | 351 | 5.860 |
| CS | 6.5 | 109.13 | 7.38 | 185 | 263 | 5.572 |
| CS | 7.8 | 109.50 | 6.30 | 195 | 222 | 5.402 |

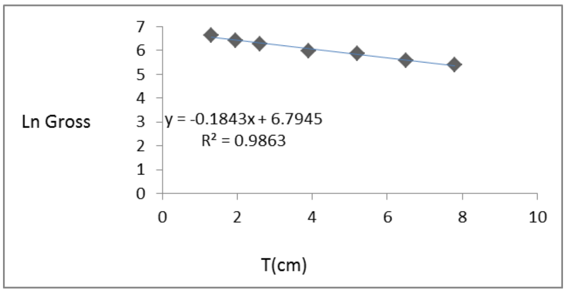


**Fig. 9: Relationship between thickness T(cm) and Ln Gross for coincidence measurements of Cu at the 1173keV gate.**

## 5 - Discussion

Table (7) summaries the results of this study for the values of l.a.c and m.a.c for both direct and coincidence spectra measurements at the three studied energies for copper. Also the table gives values of the ratio µm (co) / µm (dir) for the studied gates. The results show that both l.a.c and m.a.c values for direct and coincidence spectra decrease with the increase in energy indicating that the values obtained from coincidence spectra also follow the general behavior of attenuation with energy.

A comparison between the µm (co)/µm (dir) ratio of Cu results of this study and those of Pb measurements of Ref. [5] for the same energy gates shows a very near agreement of the values at the energies 1173 and 1332keV, while there is some difference (though not high) for the 511keV gate.

For coincidence spectra measurements we have used the gross peak areas because the background here nearly diminishes, while the NPA were used for direct spectra. For coincidence spectra, these show good quality accumulation of data, the peaks are very clear and no significant effect of chance coincidence seems to appear. It may be concluded from this study that the coincidence method can be used as an additional method besides the direct measurement in attenuation studies.

**Table 7: l.a.c and m.a.c and ratios for the energies 511, 1173 and 1332keV.**

| E(keV) | µ (dir) ($cm^{-1}$) | µ (co)($cm^{-1}$) | µm (dir) cm²/g | µm (co) cm²/g | R = µm (co) /µm (dir) |
|---|---|---|---|---|---|
| 511 | 0.5035 | 0.3846 | 0.0561 | 0.0429 | 0.7638 |
| 1173 | 0.2143 | 0.1907 | 0.0239 | 0.0212 | 0.8900 |
| 1332 | 0.1972 | 0.1843 | 0.0220 | 0.0205 | 0.9345 |

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# قياسات معامل التوهين الكتلي للامتصاص الكهروضوئي لأشعة كاما في النحاس باستخدام تقنية التطابق

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*قسم الفيزياء ، كلية التربية للعلوم الصرفة ، جامعة تكريت ، تكريت ، العراق*

**الملخص**

قيست معاملات التوهين الكتلي (م.ت.ك) للامتصاص الكهروضوئي لأشعة كاما في النحاس باستخدام مطياف تطابقي من كاشفين "3"x3 NaI(Tl) عند بوابات الطاقة 511 ، 1173 و 1332 (keV) ومصدري Na-22 و Co-60 النقطيين. ان (م.ت.ك) بوحدة (cm²/g) المقاسة بطريقة التطابق كانت اقل من تلك التي بالقياس المباشر. اظهرت قياسات التطابق المعاملات 0.0429 ، 0.0212 و 0.0205 والقياسات المباشرة المعاملات 0.0561 ، 0.0239 و 0.0220 للطاقات المدروسة على التوالي. ان نسب µm (dir)/µm (co) كانت 0. 763 ، 0.8900 و 0.9345 عند الطاقات الثلاث المذكورة على التوالي. ان المعاملات بطريقة التطابق تتصرف ايضا كما في الاطياف المباشرة مع التغير في الطاقة.