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Beta Counting and Spectroscopy

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الملخص:

الأهداف الرئيسية من هذه الورقة البحثية هي دراسة أداء وخصائص جسيمات بيتا من خلال ملاحظة طيف الطاقة لجسيمات بيتا مع قياس مدي انبعاثية هذه الجسيمات من المصادر الإشعاعية الآتية: الكوبالت -60, الاسترنشيوم -90. هذه الدراسة انجزت باستخدام نوعين من الكواشف وهما: كاشف يوديد الصوديوم (Na TI) وجهاز جيجر مولر (G-M)، تم معايرة جهاز محلل متعدد القناة (MCA) باستخدام طاقتي أشعة جاما للمصدرين: السيزيوم- 137, والصوديوم- 22. بالإضافة للذي سبق تم تجميع أطياف جسيمات بيتا المنبعثة من المصادر الإشعاعية المذكورة أعلاه لحساب نصف العمر ونهاية نقطة الطاقة لعنصر اليود- 128. في هذه التجربة تم أيضا حساب مدي اختراق جسيمات بيتا لألواح من الالومنيوم مختلفة السمك باستخدام معادلات تم إدراجها في نظرية هذه التجربة ومقارنتها بالقيم المتحصل عليها عمليا.

Abstract

The main objectives of this paper were to study the performance and properties of beta particles by observing a β particle energy spectrum and to measure the range of a beam of beta particles emitted from the two given sources (^{90}Sr and ^{60}Co). This experiment was achieved by using two detectors which are the crystal of sodium iodide detector Nal(TI) and the Geiger Muller tube (G-M). The calibration of the Multi Channel Analyser (MCA) had been done using the known energies of the ^{22}Na and ^{137}Cs gamma rays. Furthermore, the spectra of β-particles were collected in order to determine both of the half- life time and the end-point energy of ^{128}I, which found to be (23.1 minutes) and 2.19751 MeV respectively. In addition, both of the range and the half value thickness of beta particles were calculated by using different thicknesses of aluminium plates. And then, the measured values were compared to the calculated values that derived from the empirical equations which will be indicated in the theory section of this experiment.

Introduction:

Beta particles are emitted by the unstable nucleus of the radioactive atom. And they have either positive charge called positrons (β^+) or negative charge called electrons (β^-) which are emitted from the nuclei [2,5]. The beta particles are high energy electrons that emitted by neutron rich nuclei; Despite they can be emitted by an internal conversion process, the energy of the β-particle will not be unique and will have a maximum value, such as 0.54 MeV for ^{90}Sr and 0.3 MeV for ^{60}Co [2].

These particles can interact with an orbital electrons as well as nuclei in the medium through which are travelling. These interactions are most important. Therefore, Coulomb repulsion that occurs between orbital electrons and beta particles are commonly resulted in ionization process. In this process, the beta particle loses a part of energy equal to the kinetic energy of the electron and the energy used to release it from the atom. So,

beta particles may generate many ion pairs before its kinetic energy is totally dissipated [3].

Beta particles reveal many characteristics, which makes their presence detectable such as X-ray radiation associated with the slowing down of the electron (β^-) or the annihilation photons (511 keV) emitted when the positron collides the electron. Moreover, as alpha particles, betas have a characteristic average travelling distance (range) through the matter which is dependent on the initial kinetic energy. The beta particle range in air may be expressed as long as several meters[1].

In this experiment, the properties of beta particles were investigated by collecting beta particle energy spectra, in order to find both the half-life and the end-point of iodine-128. Furthermore, the range of a beam of beta particles was determined and both results and discussions will be presented and investigated.

Brief Theory

The most basic beta decay phenomenon is the conversion of a neutron into a proton (β^-) or of a proton into neutron (β^+) or an orbital electron capture. These processes are indicated as below:

$n \rightarrow p + e^-$ (negative beta decay β^-)

$p \rightarrow n + e^+$ (positive beta decay β^+)

$p + e^- \rightarrow \varepsilon$ (electron capture ε)

These processes are not complete, for there is yet another particle (a neutrino or antineutrino) which are associated in each [2].

The energies of beta particles can be determined from the measurements of their absorption in matter. Aluminium plates are the most commonly used for absorb beta particles [4]. The result of this experiment will indicate that there is a continuous energy distribution in the emission of beta particles. So, it will be quite difficult to determine the range of a beam of beta particles emitted from a radioactive source. Moreover, the gamma or X-ray may be emitted by the beta particle. These photons may be transport to a greater distance through the absorber than the characteristic beta particles. Thus, it will be difficult to expect the range of the electron from a beta source, so there are several empirical equations are used instead. These expressions are related between the maximum range (R) and the end- point energy of beta particles (E) [5].

If $E > 0.8$ MeV and $R > 0.3 g/cm^2$

Then, $R = (0.542 \times E) - 0.133$ (1)

And at lower energies, elastic scattering and ionisation losses are more important.

So, if $E < 0.8$ MeV and $R < 0.3$ g/cm^2

Then, $R = 0.407 \times E^{1.38}$ (2)

Where, R is expressed in g/cm^2 and E in MeV

In addition, the half value thickness can be calculated by using the following empirical equation:

$$t_{1/2} = 0.046 \times E^{3/2} \quad g/cm^2 \qquad (3)$$

Finally, to find the half life of ^{128} I, determine the decay constant (λ) of the source. This constant is derived from the exponential equation that appeared when plotting a graph of subtracted counts (C_T) versus time. This equation should be similar to the following equation:

$$I(t) = I_0 \exp(-\lambda t) \qquad (4)$$

Where, I(t) is presented as the number of radioactive atoms remaining at counting time t while I_0 is presented the number of activated atoms present at t=0 .

So, after determining the decay constant (λ), it can be easily to calculate the half-life of iodine-128 using the following formula:

$$^{128}\text{I half-life} = \ln 2/\lambda \qquad (5)$$

Experimental Methods

3.1. Beta particles Spectroscopy:

For first part of the experiment, the sodium iodide Nal (TI) detector was used and the photomultiplier tube was connected to a preamplifier, high voltage supply (HV) and shaping amplifier. The starting point of this part was determined by placing a ^{137}Cs source (code S112.PH) a few centimetres away from the crystal of Nal(TI) detector inside the chamber. Therefore, the ^{137}Cs spectrum was collected and the HV was adjusted until the ^{137}Cs full energy peak (662 keV γ-ray) was located at approximately 1/3 full scale. In this case, the HV value was adjustable to 560 V and was recorded to be used in the next steps.

Secondly, the ^{137}Cs was replaced with a ^{22}Na source (code S272.PH) which has two peaks 511 keV (annihilation photon) and 1247 keV (gamma ray).

And then, the ^{22}Na spectrum was recorded over the ^{137}Cs spectrum and it was left for a long time (eg, 600s) until the three peaks of ^{137}Cs and ^{22}Na were clearly appeared in order to do calibration for the MCA; these peaks were one peak at (662 keV) for ^{137}Cs while two peaks at (511 keV and 1274 keV) for ^{22}Na.

Next step, the HV was turned down to zero volts and the detector crystal was de-mounted from the photomultiplier tube by the laboratory supervisor and then be packed in a waterproof and lowered into the Am/Be neutron source tank which is located in the unsealed sources laboratory. After that, the detector crystal was left under irradiation for 10 minutes to build up sufficient β-emitter (iodine-128) in the crystal. At the end of 10 minutes, crystal was removed from the Am/Be tank and re-assembled it with the photomultiplier tube where the detector was connected again to its electronics. And then the HV was turned back to its original value (560V).

Next, the previous spectrum was deleted and the MCA preset time was set to 2500 seconds in order to acquire a new spectrum. The curser was positioned into the channel that equal to 500 keV and the total count was recorded every 60 seconds until 1800 seconds (around 30 minutes).

These counts represent the cumulative total (C_T) of beta particles that emitted with energy of around 500 keV. After 30 minutes has completed, the spectrum curve was extrapolated in order to record the end-point of β-particles. And then the graph of subtracted counts versus time was plotted to find the decay constant (λ) and use it in equation (5) to determine the half-life of iodine-128.

Finally, without deleting the previous spectrum, the ^{22}Na and ^{137}Cs sources were placed together in the chamber in order to recalibrate the detector and to evaluate the damage that might be caused by neutron activation (the recalibration spectrum is indicated in the Appendix).

3.2. β-particle Range:

For this part of the experiment, the G-M tube detector and a set of aluminium absorbers were used. At the beginning of this part, a ^{90}Sr source (code S269.PH) was placed inside the chamber at the bottom (55 mm from the detector window); this source emits a β-particle with a maximum energy of 0.54 MeV. And then the count was recorded for 60 seconds without setting any absorbers between the ^{90}Sr source and the detector.

Next, a set of aluminium plates which have a different thicknesses were placed one by one on the second shelf inside the chamber between the source and the detector. For each thickness, the count was recorded for 60s until it reached to background level. After that, the ^{90}Sr was replaced with a ^{60}Co source (code S318.PH) which emits two γ-rays at energies of 1.173 MeV and 1.332 MeV as well as a β-particle with a maximum energy of 0.31 MeV. And then the count was recorded again for every 60s by using the same geometry as before. With each source, the graphs of count rate versus absorber thickness were plotted and the maximum range of beta particles was calculated and measured as well.

In the second section of this part, ^{90}Sr was used again and the counts were recorded by using two ways. The first way was when the absorbers are located separately at the top near to the G-M tube and the second one when the absorbers are placed at the bottom near to the ^{90}Sr source. In each case, the graphs of count rate versus absorber thickness were plotted as before in order to measure the half value thickness.

Finally, the brass plate was used in the final part of this experiment to collimate the beam of beta particles. The ^{90}Sr source was still located on the bottom shelf of the chamber as before while the brass plate was placed on the second shelf between the detector and the source. In addition, an aluminium plate with thickness of 0.65 mg/cm^2 was placed once directly on the brass plate and another close to the G-M tube detector. In each case, the count rate was recorded.

Results and Discussions:

Beta particles Spectroscopy:

Figure (1) shows the energy calibration spectrum using three peaks of both ^{137}Cs and ^{22}Na sources.

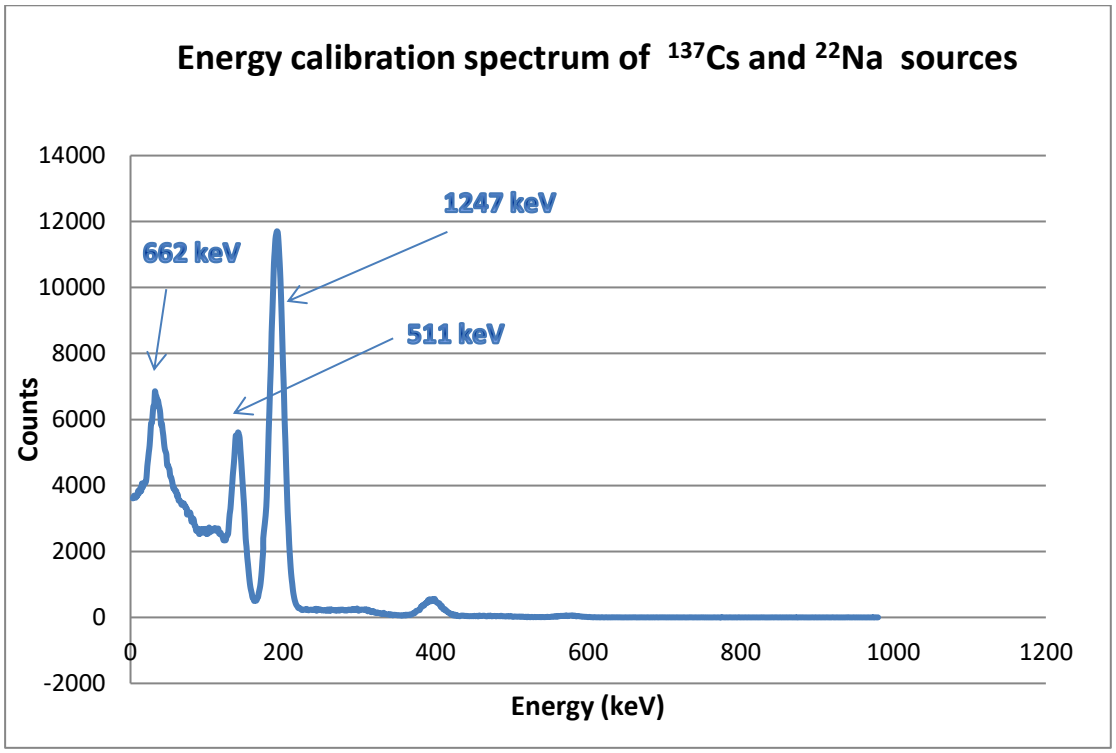

Figure (1) energy calibration spectrum using both ^{137}Cs and ^{22}Na sources

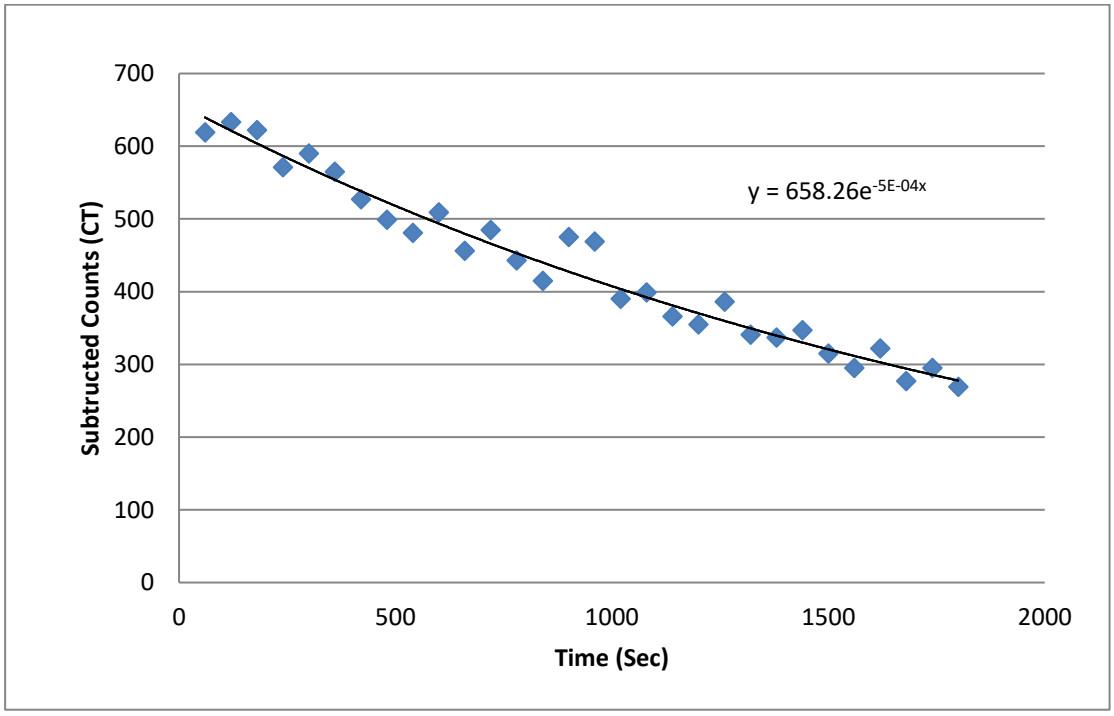

Figure (2) subtracted counts versus time to find decay constant of ^{128}I

The collected data from beta particle spectroscopy are demonstrated in figure (2) in order to determine the decay constant (λ) of iodine-128 which found to be (5E-04) or (0.0005) from exponential trend line equation of the plot. By using this value in the equation of half-life time, the half life time of ^{128}I is calculated and found to be:

$$^{128}\text{I half-life} = \frac{\ln 2}{\lambda} = \frac{0.693}{0.0005} = 1386.3\text{seconds} = 23.1\text{minutes}$$

From this result, it can be noticed that there is not a significant different between this value and the actual value of the half life of ^{128}I which is 25 minutes.

In addition, from the beta spectrum which is indicated in figure (3), the end-point energy of ^{128}I was determined as well and found to be (2.19751 MeV) which is very similar to the expected value of around (2.2 MeV).

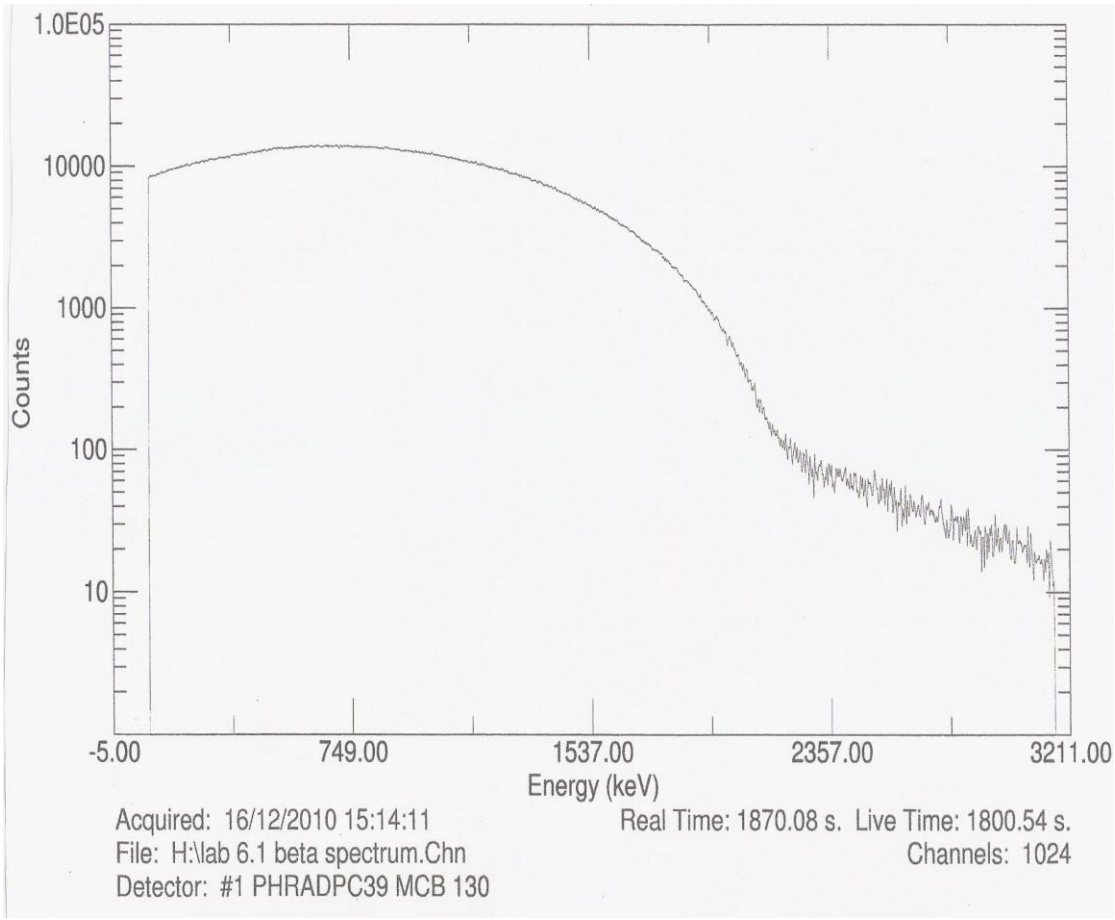

Figure (3): Beta spectrum [1]

β-particles Range:

In this part of the experiment, ^{90}Sr and ^{60}Co sources were used to determine the maximum range of beta particles. Therefore, figure (4) demonstrates the attenuation spectrum of beta particles for the ^{90}Sr source by using different thicknesses of aluminium plates.

It can be seen from this figure that the counts decrease sharply from 17.4 to approximately 0.7 with increasing in the absorbers thickness from (0 mg/cm^2) to (508 mg/cm^2). The

counts which are recorded after (508 mg/cm^2) thickness were remaining stable which are the counts of the background level; this means that the highest thickness of the plates was able to stop beta particles that are emitted from the ^{90}Sr source.

While figure (5) shows the attenuation spectrum for the ^{60}Co source which emits two gamma rays as well as a beta particles. It can be observed from this figure which is similar to figure (4), the counts decrease exponentially as increasing in the thickness of the plates, but the value of these counts are greater than the counts recorded form the ^{90}Sr source, This is due to the emission of gamma ray which cannot be stopped by similar thickness of the aluminium plates.

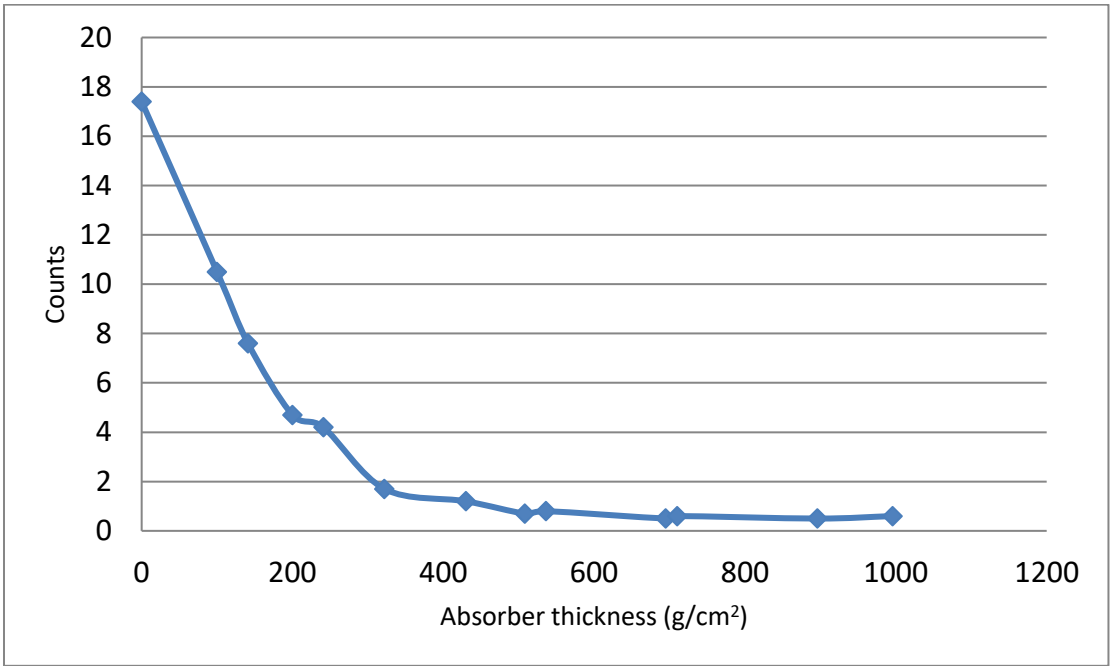

Figure (4) the attenuation of beta particles for the ^{90}Sr source.

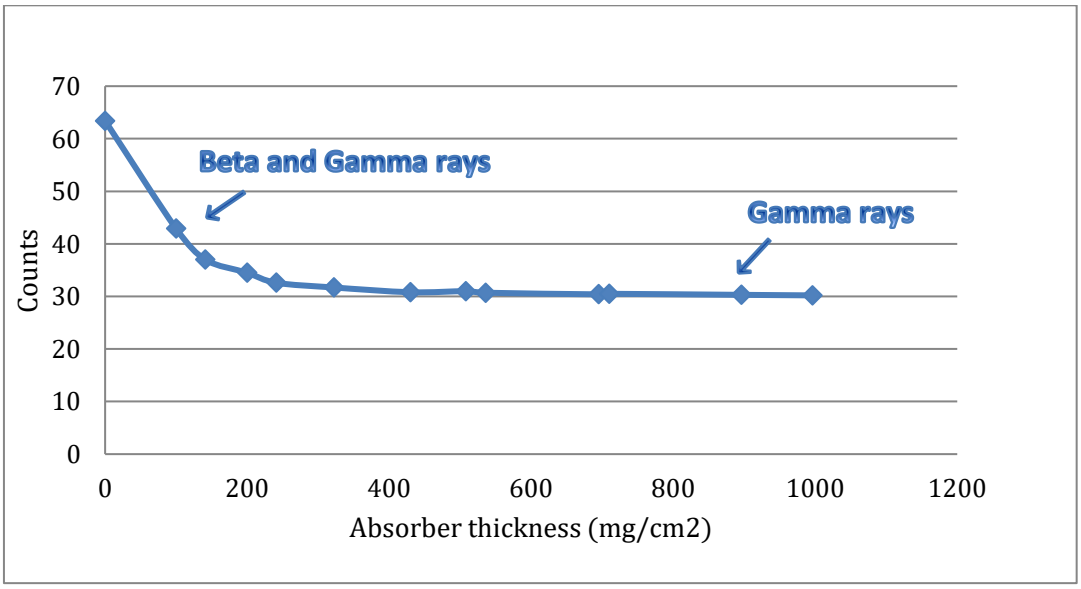

Figure (5) the attenuation of beta particles for the ^{60}Co source.

The calculation of the maximum range of beta particles was done by using the following empirical equations as below:

For ^{90}Sr

When, (E < 0.8 MeV), E= 0.54 MeV

Then, $R = 0.407\ E^{1.38}$

$= 0.407 \times (0.54)^{1.38}$

$= 0.173899\ g/cm^2$

For ^{90}Y (the daughter of ^{90}Sr)

When, (E> 0.8 MeV), E=2.25 MeV

Then, $R= (0.542 \times E) - 0.133$

$= (0.542 \times 2.25) - 0.133$

$= 1.0865\ g/cm^2$

And, For ^{60}Co

When, (E< 0.8 MeV), E= 0.31 MeV

Then, $R = 0.407\ E^{1.38}$

$= 0.407\ (0.31)^{1.38}$

$= 0.08\ g/cm^2$

From this calculation, it can be observed that there is a considerable difference in the range calculated of ^{90}Sr and ^{90}Y. This difference may be due to the various energies of β-particles that are emitted from ^{90}Sr and ^{90}Y as well as the continuing of the spectrum beta, which make the discrimination between the energies of ^{90}Sr and ^{90}Y was impossible inside the matter. Moreover, Because of the emission of γ-ray that emitted from the ^{60}Co source, it was also difficult to investigate the endpoint. However, the maximum range of beta particles emitted from the ^{60}Co source has been calculated and found to be 0.08 g/ cm^2.This means that beta particles can be stopped at this point while gamma ray was still able to penetrate the absorber plate. This was noticeable from the G-M tube detector which was continuously recording the counts even after beta particles were stopped.

Furthermore, the calculation of the half value thickness was done by using the empirical formula as follows:

For ^{90}Sr

$t_{1/2} = 0.046 \times E^{3/2}\ g/cm^2$

$= 0.046 \times (0.540)^{3/2}$

$= 0.018\ g/cm^2$

Similarly,

For ^{90}Y (the daughter of ^{90}Sr)

$t_{1/2} = 0.046 \times (2.25)^{3/2}$

$= 0.155\ g/cm^2$

And, For ^{60}Co

$t_{1/2} = 0.046 \times (0.31)^{3/2} = 0.007\ g/cm^2$

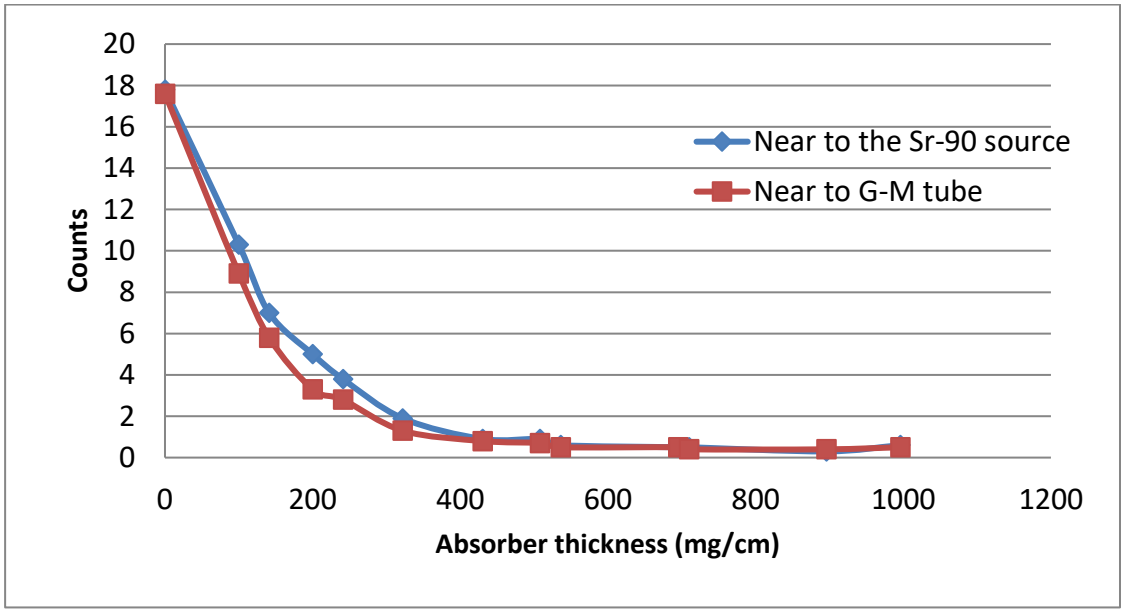

Figure (6) the attenuation of beta particles using ^{90}Sr source and two different position of the absorber.

Figure (6) illustrates two curves of the counts versus different thicknesses of the aluminium plates which were located at two different positions inside the chamber (as near to G-M tube and as near to the ^{90}Sr source).

From these curves, in general it can be seen that there is an exponential decrease in the counts as increasing in the absorbers thickness.

From the data presented in appendix 3 the values of count rate that recorded when the absorber is placed near to the ^{90}Sr source are little bet higher than that when it is located near to the G-M tube. This increase may be due to the scattering of β-particles from the aluminium absorbers.

Furthermore, by placing the brass plate and the aluminium plate of 0.65 mg/cm^2 between the ^{90}Sr and the detector, it can be noticed that brass is a sufficient material to be used in shielding applications against beta particles.

Conclusion:

In general, the properties of beta particles were investigated by collecting beta particles energy spectra. Therefore, the half life of iodine-128 has been calculated and found to be (23.1 minutes). In addition, the end point energy of β-particles emitted from ^{128}I has been determined as well which found to be (2.19751 MeV). As a result, the range of beta particles was calculated by using the empirical equations that found to be 0.173, 1.086 and 0.08 g/cm^2 respectively for ^{90}Sr, ^{90}Y and ^{60}Co sources. Furthermore, the half value thickness of beta particles has been determined by using the empirical relations and found to be 0.018, 0.155 and 0.007 g/cm^2 respectively for the same order of sources that mentioned above. Because of the emission of gamma ray from the ^{60}Co, it was very difficult to measure the half value thickness and the end point of beta particles. Finally, from the result obtained, it can be noticed that brass plate was sufficient material to be used as an efficient shield against beta particles.

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Appendix:

1. The data obtained to find the half life for Iodine-128

Time (s)	Counts	Subtracted counts
60	619	619
120	1252	633
180	1874	622
240	2445	571
300	3037	590
360	3602	565
420	4129	527
480	4628	499
540	5109	481
600	5618	509
660	6074	456
720	6559	485
780	7002	443
840	7417	415
900	7892	475
960	8361	469
1020	8751	390
1080	9150	399
1140	9516	366
1200	9871	355
1260	10257	386
1320	10598	341
1380	10935	337
1440	11282	347
1500	11597	315
1560	11892	295
1620	12214	322
1680	12491	277
1740	12786	295
1800	13055	269

2.The counts recorded using the ^{90}Sr and ^{60}Co sources and different absorber thickness.

Absorber thickness (mg/cm^2)	True mass thickness (mg/cm^2)	Counts for ^{90}Sr	Counts for ^{60}Co
0	7.15	17.4	63.4
100	107.15	10.5	42.9
141	148.15	7.6	37.0
200	207.15	4.7	34.5
241	248.15	4.2	32.6
322	329.15	1.7	31.7
430	437.15	1.2	30.8
508	515.15	0.7	31.0
536	543.15	0.8	30.7
695	702.15	0.5	30.4
710	717.15	0.6	30.5
896	903.15	0.5	30.3
996	1003.15	0.6	30.2

The counts recorded using ^{90}Sr with different absorbers which are placed at different positions.

Thickness (mg/cm^2)	The counts when absorber near to G-M tube	The counts when absorber near to the ^{90}Sr source
0	17.6	17.8
100	8.9	10.3
141	5.8	7.0
200	3.3	5.0
241	2.8	3.8
322	1.3	1.9
430	0.8	0.9
508	0.7	0.9
536	0.5	0.6
695	0.5	0.5
710	0.4	0.5
896	0.4	0.3
996	0.5	0.6