Multi Channel Analyzer (MCA)
Analyzing a Gamma spectrum

Objective:

Using the MCA to acquire spectrums for different gamma sources and to identify an unknown source from its spectrum, furthermore to investigate and analyze from the spectrum of the Cs-137 source the different aspects of the gamma rays and their interactions.

Introduction:

The multi channel analyzer is similar to the single channel analyzer in that it sorts individual detections of the same level into an energy bin or channel. However the single channel analyzer will only exam these detections for one set level of energy at a time and then must be manually adjusted to look at the detections of another energy. The multi channel analyzer will sort the detections by their energy level as they are detected. There are two time processor associated with the MCA. Real time and live time, where real time is the true elapsed time during a data collection and live time is real time minus the time the MCA was busy with the sorting process and there unavailable to detect any signal coming from the detector.

There is also a section covering Compton Scattering.

Procedure:

The ICS Universal spectrometer is a computer control MCA. To get a meaningful spectrum to determine an unknown source it first must be calibrated using two known sources.

1. Start the UCS 30 program. Turn on the UCS 30 instrument.
2. Obtain the ^{60}Co and ^{137}Cs source. Place the ^{60}Co source on the second shelf and just below it put the ^{137}Cs source. This allows both spectrums to be gathered simultaneously to obtain a spectrum for calibration.
3. From the Settings menu select Energy Calibration then uncalibrate.
4. From the Settings Menu select Amp/HV/ADC. Turn on the high voltage located in the upper left hand corner of the window and select apply. Close window.
5. Select Go data should now be accumulating observe the LT, live time, and RT, real time, allow LT gather data for 300 seconds.
6. Stop the data accumulation you should now observe the spectrum for the two sources. Of primary concern are the peaks located toward the end these are the two ^{60}Co peaks 1173keV and 1333kev respectfully and also the peak located more or less in the center of the spectrum this is the ^{137}Cs peak of 662keV.

7. Using the mouse cursor click unto the central peak of the spectrum. Under the spectrum graph will be indicators showing the channel number and number of counts. The right and left arrow keys on the keyboard will move the cursor in the associated direction also the up and down arrow keys will magnify or reduce the spectrum. Using these keys move the cursor along the peak to find the top most count. Record the channel number and assign it to the 662keV peak.

8. Move the cursor to the end two peaks, these are the ^{60}Co gamma peaks, and select the left most of these two peaks. As in the step above determine the most counts and assign that channel to 1173keV. Lastly do the same for the other peak and assign the channel to 1333keV.

9. From the settings menu select Energy Calibrate, 3 point.

10. For point 1 enter the ^{137}Cs channel and its energy. Point 2 and 3 respectfully need to be assigned with channel numbers and their respective energy. The MCA is now calibrated and ready.

11. Take individual spectrums for each source and save the spectrums as a tab delimited file so that it can be plotted later. Obtain the unknown source and acquire a spectrum for it as well. The small peak at the end is one of the primary peaks of this source.

The scintillation tube is not as sensitive in the high energy regions and therefore the peak in this region is not as prominent.

Identify the unknown source using the table with given gamma energies.

Data Analysis

Use the file for Compton Scattering along with the data for the individual sources.

Identify the photo peak(s), their Compton edge(s), Compton valley(s), and backscattering peaks for each source.

From the Compton Scattering handout, verify equation 4.4 for each source gamma peak(s).

Determine the electron's mass-energy for each peak.

APPENDIX E

List of Commonly Observed Gamma Energies

This is a table of commonly-observed gamma energies, arranged by increasing gamma energy. The parent isotope and its half life are listed with the gamma energy. The key gamma energy for an isotope has an asterisk following it. Each isotope is listed once with its complete set of gamma energies. The gamma decay fraction is listed in parentheses It represents the number of gammas of that energy emitted per decay of the parent nucleus (as a percentage and not a fraction in this table).

Energy	Element	Half Life	Associated gammas
35.5 (4.1)	Sb-125		427.9*(30)
44.8 (31)	Pu-241		148.6*(96)
46.5*(3.9)	***Pb-210***	***22.3 y***	(U-238)
56.3 (9)	Pu-241		148.6*(96)
59.5*(35)	***Am-241***	***433 y***	***26.3***
63.3 (3.8)	Th-234		(U-238) 92.6*(5.4)
67.8 (42)	Ta-182		1221.4*(27)
69.7 (2.6)	Gd-153		97.4*(31)
79.1 (7.1)	Ag-108m		722.9*(91)
80.1 (2)	Ce-144		133.5*(11)
81.0 (33)	Ba-133		356.0*(62)
84.4*(1.2)	***Th-228***	***1.913 y***	***(Th-232)***
86.5*(31)	***Eu-155***	***4.71 y***	***105.3***
88.0*(3.7)	***Cd-109***	***462.0 d***	
88.4 (13)	La-138		1435.8*(68)
92.6*(5.4)	***Th-234***	***24.1 d***	***(U-238) 63.3***
93.3*(38)	***Ga-67***	***3.260 d***	***184.6 300.2 393.5 209***
93.4 (3.5)	Ac-228		(Th-232) 911.1*(27.7)
97.4*(31)	***Gd-153***	***241.6 d***	***103.2 69.7***
98.9*(11)	***Au-195***	***186.12 d***	***129.8***
100.1 (14)	Ta-182		1221.4*(27)
103.2 (22)	Gd-153		97.4*(31)
103.7 (30)	Pu-241		148.6*(96)
105.3 (20)	Eu-155		86.5*(31)
121.1 (17)	Se-75		264.7*(60)
121.8 (28)	Eu-152		1408.0*(21)
122.1*(86)	***Co-57***	***271.8 d***	***136.5 14.4***
123.1*(40)	***Eu-154***	***8.59 y***	***1274.5 723.3 1004.8 873.2 996.3 247.9***
129.8 (0.8)	Au-195		98.9*(11)
133.5*(11)	***Ce-144***	***284.6 d***	***80.1 696.5 (Pr-144)***
136 (57)	Se-75		264.7*(60)
136.5 (11)	Co-57		122.1*(86)
140.5*(90)	***Tc-99m***	***6.01 h***	
148.6*(94)	***Pu-241***	***14.4 y***	***44.8 103.7 44.2 56.3***
176.3 (6.9)	Sb-125		427.9*(30)
184.6 (20)	Ga-67	3.260 d	93.3*(38)
185.7*(54)	***U-235***	***7.04×10^{8} y***	***194.9 205.3 163.4***
190.3*(16)	***In-114 m***	***49.51 d***	***558.4 725.2***
192.3 (3.1)	Fe-59		1099.2*(56)

Energy	Element	Half Life	Associated gammas
201.3 (84)	Lu-176		308.9*(93)
209 (2.2)	Ga-67		93.3*(38)
209.3 (4.4)	Ac-228		(Th-232) 911.1*(27.7)
210.6 (11.3)	Th-227		(U-235) 236*(11.5)
222.1 (7.6)	Ta-182		1221.4*(27)
236*(11.5)	***Th-227***	***18.72 d***	***(U-235) 210.6***
238.6*(45)	***Pb-212***	***10.64 h***	***(Th-232)***
241.0*(4)	***Ra-226***	***3.66 d***	***(Th-232)***
244.7 (7)	Eu-152		1408.0*(21)
247.9 (6.6)	Eu-154		123.1*(40)
255.1*(1.9)	***Sn-113***	***115.1 d***	***391.7 (In-113m)***
264.7*(60)	***Se-75***	***119.78 d***	***121.1 136 279.5 400.7***
269.5*(13.6)	***Ra-223***	***11.435 d***	***(U-235)***
271.2*(10.6)	***Rn-219***	***3.96 s***	***(U-235) 401.8***
276.4 (6.9)	Ba-133		356.0*(62)
277.4 (6.8)	Tl-208		(Th-232) 2614.7*(100)
279.2*(77)	***Hg-203***	***46.61 d***	
279.5 (25)	Se-75		264.7*(60)
284.3 (6)	I-131		364.5*(81)
295.2 (19.2)	Pb-214		(U-238) 351.9*(37.2)
300.1 (4)	Th-228		2614.5*
300.2 (16)	Ga-67		93.3*(38)
302.8 (19)	Ba-133		356.0*(62)
308.9*(93)	***Lu-176***	***3.6 x 10^{10} y***	***201.8***
320.1*(9.8)	***Cr-51***	***27.7 d***	
338.3 (11.4)	Ac-228		(Th-232) 911.1*(27.7)
344.3 (27)	Eu-152		1408.0*(21)
351.1*(12.9)	***Bi-211***	***2.14 m***	***(U-235)***
352.0*(37.2)	***Pb-214***	***26.8 m***	***(U-238) 295.2***
356.0*(62)	***Ba-133***	***10.53 y***	***81 302.8 383.9 276.4***
364.5*(81)	***I-131***	***8.04 d***	***637 284.3 722.9***
383.9 (8.7)	Ba-133		356.0*(62)
391.7*(65)	***In-113m***	***1.658 hr***	
393.5 (4.5)	Ga-67		93.3*(38)
400.7 (12)	Se-75		264.7*(60)
401.8 (6.5)	Rn-219		(U-235) 271.2*(10.6)
416.9 (32)	In-116		1293.6*(75)
427.9*(30)	***Sb-125***	***2.758 y***	***600.6 635.9 463.4 176.3 35.5 606.6***
433.9 (90)	Ag-108m		722.9*(91)
442.9*(16)	***I-128***	***25 m***	***526.6***
463.4 (10)	Sb-125		427.9*(30)
477.6 (10)	***Be-7****	***53.3 d***	
510.8 (21.6)	Tl-208		(Th-232) 2614.7*(100)
511.0 (180)	Na-22		1274.5*(100)
511.0 (30)	Co-58		810.8*(99)
511.0 (2.8)	Zn-65		1115.5*(50.8)
511.0 (0.6)	Ag-108		633*(1.8)
526.6 (1.5)	I-128		442.9*(16)
558.4 (4.5)	In-114 m		190.3*(16)
563.2 (8.4)	Cs-134		795.8*(85.4)
569.3 (15.4)	Cs-134		795.8*(85.4)
569.7*(98)	***Bi-207***	***38.0 y***	***1063.6 1770.2***
583.1 (84.2)	Ti-208		(Th-232) 2617.5*(100)
600.6 (18)	Sb-125		427.9*(30)
602.7*(98)	***Sb-124***	***60.2 d***	***1691 722.8 645.9 2091 1368.2***
604.7 (97.6)	Cs-134		795.8*(85.4)
606.6 (5)	Sb-125		427.9*(30)
609.3*(46.3)	***Bi-214***	***19.9 m***	***(U-238) 1764.5 1120.3 1238.1 2204.2***
614.4 (91)	Ag-108m		722.9*(91)
633*(1.8)	***Ag-108***	***2.39 m***	***433.9 511***
635.9 (11)	Sb-125		427.9*(30)
637.0 (7.3)	I-131		364.5*(81)

Energy	Element	Half Life	Associated gammas
645.9 (7.3)	Sb-124		602.7*(98)
657.8 (4.4)	***Ag-110***	***24.6 s***	
661.6*(90)	***Ba-137m***	***2.55 m***	
661.6*(85)	***Cs-137***	***30.17 y***	
696.5 (1.5)	***Pr-144***	***17.3 m***	***133.5*(11) (Ce-144)***
722.8 (11)	Sb-124		602.7*(98)
722.9*(91)	***Ag-108m***	***130 y***	***614.4 433.9 79.2***
722.9 (1.8)	I-131		364.5*(81)
723.3 (19)	Eu-154		123.1*(40)
725.2 (4.5)	In-114 m		190.3*(16)
727.2*(11.8)	***Bi-212***	***60.6 m***	***(Th-232)***
778.9 (13)	Eu-152		1408.0*(21)
788.7 (32)	***La-138***	***1.05 x 10^{11}y***	
795.8*(85.4)	***Cs-134***	***2.065 y***	***604.7 801.9 569.3 563.3***
801.9 (8.7)	Cs-134		795.8*(85.4)
810.8*(99)	***Co-58***	***70.88 d***	***863.9 511***
818.7 (15)	In-116	54.2 m	1293.6*(75)
834.8*(100)	***Mn-54***	***312.2 d***	
860.4 (12.5)	Tl-208		(Th-232) 2614.7*(100)
863.9 (1.8)	Co-58		810.8*(99)
873.2 (12)	Eu-154		123.1*(40)
889.3 (100)	Sc-46		1120.5*(100)
898.0 (93)	Y-88		1836.0*(99)
911.1*(27.7)	***Ac-228***	***6.15 h***	***(Th-232) 969.1 338.3 209.3 93.4***
964.0 (15)	Eu-152		1408.1*(21)
969.1 (16.6)	Ac-228		(Th-232) 911.1*(27.7)
996.3 (11)	Eu-154		123.1*(40)
1004.8 (18)	Eu-154		123.1*(40)
1063.6 (75)	Bi-207		569.7*(98)
1085.8 (10)	Eu-152		1408.0*(21)
1097.3 (54)	In-116		1293.6*(75)
1099.2*(56)	***Fe-59***	***44.51 d***	***1291.6 192.3***
1112.0 (13)	Eu-152		1408.0*(21)
1115.5*(50.8)	***Zn-65***	***243.8 d***	***511***
1120.3 (15.1)	Bi-214		(U-238) 609.3*(46.3)
1120.5 (100)	Sc-46		889.3*(100)
1121.3 (35)	Ta-182		1221.4*(27)
1173.2 (100)	Co-60		1332.5*(100)
1189.1 (16)	Ta-182		1221.4*(27)
1221.4****(27)***	***Ta-182***	***114.43 d***	***67.8 1121.3 1189.1 100.1 222.1 1230.9***
1238.1 (5.9)	Bi-214		(U-238) 609.3*(46.3)
1274.5 ****(100)***	***Na-22***	***2.605 y***	***511***
1274.5 (36)	Eu-154		123.1*(40)
1291.6 (43)	Fe-59		1099.2*(56)
1293.6 *(75)	***In-116***	***54.2 min***	***1097.3 416.9 2112.1 818.7 1507***
1332.5*(100)	***Co-60***	***5.271 y***	***1173.2*(100)***
1368.2 (2.5)	Sb-124		602.7*(98)
1408.0*(21)	***Eu-152***	***13.48 y***	***121.8 344.3 964 1112 778.9 1085.8 244.7***
1434.1*(100)	***V-52***	***3.76 m***	
1435.8*(68)	***La-138***	***1.05 x 10^{11} y***	***88.4 788.7***
1460.8*(11)	***K-40***	***1.28 x 10^{9} y***	
1507.4 (10)	In-116	54.2 m	1293.6*(75)
1691*(49)	***Sb-124***		***602.7*(98)***
1764.5 (15.8)	Bi-214		(U-238) 609.3*(46.3)
1770.2 (6.8)	Bi-207		569.7*(98)
1779*(100)	***Al-28***	***2.25 m***	
1836.1*(99)	***Y-88***	***106.6 d***	***898.1***
2091 (5.7)	Sb-124	60.2 d	602.7*(98)
2112.1 (18)	In-116		1293.6*(75)
2204.2 (5)	Bi-214		(U-238) 609.3*(46.3)
2614.7*(100)	***Tl-208***	***183 s***	***(Th-232) 583.1 510.8 860.5 277.4***
2677.9 (2)	Rb-88		1836.0*

Compton Scattering

INTRODUCTION

There is more structure in your spectra than the photopeaks used in the last few experiments. Looking back at an earlier spectrum of ^{137}Cs, you will notice a small peak, or more precisely an edge, at about 477 keV. This is marked as the Compton Edge in Figure 4.1. Depending upon the geometrical arrangement of your detector and source, there is probably a photopeak at about 185 keV. There is only one gamma energy from ^{137}Cs, yet the observed spectrum has a photopeak at 661.6 keV, and these two Compton structures, an edge at 477 keV and a peak at 185 keV. How does this happen? It is due to Compton scattering by electrons.

The Compton effect is a "collision" of the gamma photon with an atomic electron in which relativistic mass-energy and momentum are conserved. After the collision, the electron can have a kinetic energy that is a large fraction of the gamma's original energy, E_γ . The gamma loses this energy, becoming a lower frequency wave with energy, $E_{\gamma'}$. The relation between the gamma's energy before the collision compared to after the collision is

4.1 $$\frac{1}{E_{\gamma'}} - \frac{1}{E_\gamma} = \frac{(1-\cos\theta)}{m_e c^2}$$

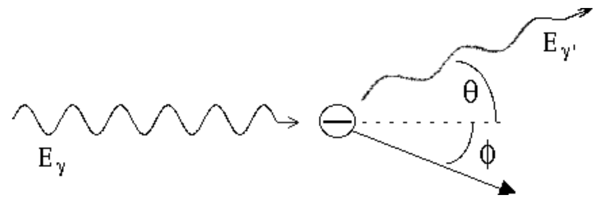

Figure 4.2. *Compton-scattering collision between an incoming photon, E_γ, and a stationary electron. This results in a lower energy photon, $E_{\gamma'}$, scattered through angle θ, and the electron scattered through angle ϕ.*

where $m_e c^2$ is the rest mass energy of the electron (511 keV) and θ is the angle through which the gamma is deflected. A depiction of the Compton scattering is shown in Figure 4.2.

What is the origin of the Compton edge at 477 keV? A gamma enters the crystal of the detector and Compton scatters off an electron. The Compton-scattered gamma leaves the detector, so the amount of detected energy is the kinetic energy given to the electron. The maximum kinetic energy given to the electron, E_{max}, results from a "head-on" collision with the gamma, scattering the gamma photon backwards ($\theta = 180^\circ$). From equation 4.1 this maximum electron energy is

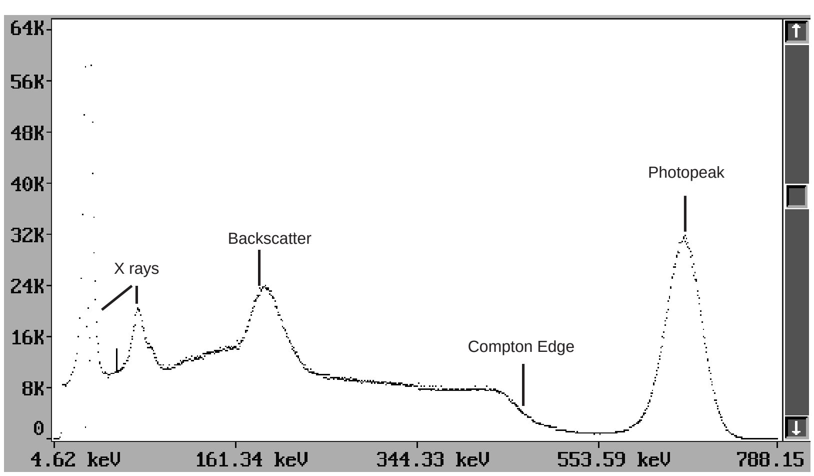

Figure 4.1. *Gamma spectrum from the decay of ^{137}Cs.*

4.2 $$E_{max} = E_{\gamma} - E_{\gamma\copyright} = \frac{2E_{\gamma}^{2}}{2E_{\gamma} + m_{e}c^{2}}$$

The Compton edge represents this maximum energy given to the electron. Of course the electron may suffer a gentler collision and have less than the maximum energy after the collision. This is the origin of the broad distribution of events at energies less than the Compton edge.

If you have a peak at 185 keV, it is due to gammas that interact with an electron outside the detector. The gammas Compton-scatter back into the detector, where they are detected by the photoeffect. Only a few angles near 180° result in scattering into the detector, so that a peak results (at $E_{BS} = E_{\gamma'}$). This is called the Compton backscattering peak. It is shown in Figure 4.1 as Backscatter.

Energy conservation requires that the sum of the Compton edge energy and the backscattering energy be equal to the original gamma energy (photopeak energy).

OBJECTIVE

Collect gamma spectra from several commercial radioactive sources with single photopeaks and measure the gamma energies of the (photoeffect) peaks, Compton backscattering peaks and the Compton edges. From these energies, the rest mass energy of the electron can be determined.

SUPPLIES

- NaI(Tl) detector with MCA
- Radioactive sources ^{54}Mn, ^{65}Zn, ^{137}Cs, ^{22}Na, ^{40}K, ^{207}Bi

SUGGESTED EXPERIMENTAL PROCEDURE

1. Perform an energy calibration of your detector as you did in Experiment #1. Adjust the gain to include energies out to 1,800 keV.
2. Place a radioactive source near your detector. Acquire a spectrum from each available source.
3. Place a thick lead absorber (say 3-10 mm) a few centimeters beneath the source to sandwich the source between the lead and the detector. Again acquire spectra from all sources used in step 2.

DATA ANALYSIS

For each source measure the photopeak energy, E_{γ}, Compton edge, E_{max}, and its minimum backscatter peak energy, E_{BS}. The Compton edge, E_{max}, is at an energy corresponding to about half the change in the count rate from the trough between the photopeak and edge, to the immediate maximum in the edge(see Figure 4.1). The photopeak is found in the usual manner with a ROI, while the backscatter peak is treated differently. The backscatter peak is more triangular and asymmetric in shape, with the peak flat or slightly rounded. The energy of the backscatter peak corresponds to the lowest energy of the top of the peak. The Compton edge and the backscatter peak positions are marked in Figure 4.1.

Test your energy measurements in each spectrum to see that

4.3 $$E_{\gamma} = E_{\gamma\copyright} + E_{\max} = E_{BS} + E_{\max}$$

Solve equation 4.2 for $m_e c^2$ as a function of E_{γ} and E_{max}. Using the photopeak and Compton-edge energies calculate the mass energy of the electron and the measurement error in that mass from equation 4.2. Average your results to obtain one value for the electron's rest mass energy and the standard deviation in that value.

The backscatter peak in each spectrum should have changed in intensity with the addition of the lead sheet. Could any other material work as well? It is the product of the electron density and the material thickness that correlates directly with the intensity of the backscatter peak.

Solve equation 4.2 for $m_e c^2$ as a function of E_{γ} and $E_{\gamma'}$, where $E_{\gamma'}$ and E_{BS} are the same for 180° scattering. Use your measured energies to determine $m_e c^2$. How well does the average of these values compare to the average from the Compton-edge data?

Equations 4.1 and 4.2 are derived from the relativistic mass-energy and momentum conservation laws. Much can be learned from the same data with the nonrelativistic energy and momentum conservation laws. Try the following reanalysis of your data.

DATA ANALYSIS, A CLASSICAL APPROACH

Let us apply the equations for classical kinetic energy ($T = 1/2\ mv^2 = p^2/2m$) to energy and momentum conservation for 180° Compton scattering. From this we can devise a way to calculate the electron's mass energy, m_ec^2.

Energy conservation gives

4.4 $$E_\gamma = E_{BS} + T$$

where T is the electron's kinetic energy, $T = E_{max}$, E_γ is the gamma's original energy, and E_{BS} is the gamma's energy after Compton scattering. Momentum conservation gives

4.5 $$p_\gamma c = p_e c - p_{\gamma'} c$$

where p_γ, p_e, and $p_{\gamma'}$ are the incident-photon, scattered-electron, and scattered-photon momenta, respectively. Using the classical relationship between energy and momentum for a photon, E = pc, equation 4.4 with 4.5 becomes equation 4.6.

4.6 $$p_e c = 2E_\gamma - T$$

Assuming that the electron's kinetic energy, T, is related to its momentum by the classical relationship, then equation 4.6 becomes

4.7 $$2Tm_ec^2 = (p_ec)^2 = (2E_\gamma - T)^2$$

from which we find

4.8 $$m_ec^2 = \frac{(2E_\gamma - T)^2}{2T} = \frac{(2E_\gamma - E_{\max})^2}{2E_{\max}}$$

Use your measurements of the photopeak energies, E_γ, and their associated Compton-edge energies, E_{max}, to calculate the electron's mass-energy, m_ec^2. What do you expect for an answer? Create a graph of m_ec^2 as a function of T (which is E_{max}). Perform the usual analysis and explain your results to someone. These results are quite exciting!

Einstein's work in special relativity suggests that the mass-energy of a particle, E , is related to its rest mass energy, m_ec^2, by

4.9 $$E = \gamma\ m_ec^2$$

where

4.10 $$\gamma = \frac{1}{\sqrt{(1 - v^2/c^2)}}$$

Does this explain why your measured electron masses are not constant? How well do equations 4.9 and 4.10 model your data?