FÍSICA EXPERIMENTAL IV

Laboratório de Física Moderna

ESPECTROSCOPIA de RAIOS g

Efeitos Fotoeléctrico e de Compton, e Produção de Pares e^+e^-

1. INTRODUÇÃO E OBJECTIVOS

O objectivo deste trabalho é o estudo da interação da radiação com a matéria, através dos processos fotoeléctrico, de Compton e produção de pares (este só tem lugar se $E_\gamma > 1022$ keV).

Usa-se um espectrómetro simples, formado por uma fonte emissora de raios γ e um detector de iodeto de sódio activado por tálio - NaI(Tl) - com fotomultiplicador acoplado, ao qual se segue a cadeia electrónica, composta por gerador de alta tensão (regulado a ~ 900 V), amplificador de tensão e placa multicanal inserido em PC com software de aquisição de dados.

O trabalho divide-se nas seguintes partes:

1) Calibração em energia com o auxílio de duas fontes conhecidas: ^{60}Co, ^{137}Cs**.** Devem usar-se, além dos valores dos seus picos fotoeléctricos (1333 e 1173 keV; 662 keV), o da radiação X de 32 keV.
2) Aplicação da calibração à determinação das energias dos picos de retrodifusão e dos "joelhos" de Compton dos espectros de energia. das fontes de ^{60}Co e ^{137}Cs; comparação com os valores calculados e/ou tabelados.
3) Estudo do espectro de γs de alta energia do ^{208}Tl (fonte de ^{228}Th e descendentes): obtenção das energias dos seus picos fotoeléctrico, de escape simples e de escape duplo e comparação com os valores do nuclídeo em causa.
4) Estudo da atenuação de gamas na matéria.

2. GAMMA SOURCES

Most isotopes that are used for gamma measurements also have betas in their decay schemes. The typical decay scheme for the isotope will include a beta decay to a particular level followed by gamma emission to the ground state of the final isotope. The beta particles will usually be absorbed in the surrounding material and not enter the scintillator at all. This absorption is normally assured with aluminum absorbers. For this experiment the betas offer no real problem and so absorbers are not specified. There will be some beta absorption by the light shield over the phototube. The gammas, however, are quite penetrating and hence will pass easily through the aluminum light shield.

Generally there are two unknowns that we would like to investigate about a gamma source. One is the energy of the gammas from the source. The other is the number of gammas that leave the source per unit of time. In this experiment the student will become familiar with some of the basic NaI(Tl) measurements associated with gamma-emitting unknowns.

3. ENERGY CALIBRATION

3.1 Setup of Equipment

Set up the electronics in the arrangement shown in Fig.1. There are two parameters that ultimately determine the overall gain of the system: the high voltage that is furnished to the phototube and the gain of the linear amplifier. The gain of the photomultiplier tube is quite dependent upon its high voltage. A rule of thumb for most phototubes is that a 10% change of the high voltage will change the gain by a factor of 2. The high-voltage value depends on the phototube being used; consult your instruction manual for the phototube and select a value in the middle of its normal operating range. (The instructor may wish to recommend a value.)

Set the indicated modules as follows:

TC948 High Voltage: See phototube instructions and set the level at about the middle of the acceptable operating range (normally about 950 V).

TC241 Linear Amplifier: Unipolar output. The gain will be adjusted during the experiment.

Multichannel Analyzer (PC): 10-V input, 1024 channels

3.2 Experimental Procedure

1. Place the ^{137}Cs source (E_γ = 0.662 MeV) ~2 cm in front of the NaI(Tl) crystal.
2. Adjust the coarse and fine gain controls of the linear amplifier so that the 0.662-MeV photopeak for ^{137}Cs falls at about 30% of the maximum number of channels. Since the system is linear it is reasonable to assume that full scale on the multichannel analyzer now corresponds to about 2 MeV.

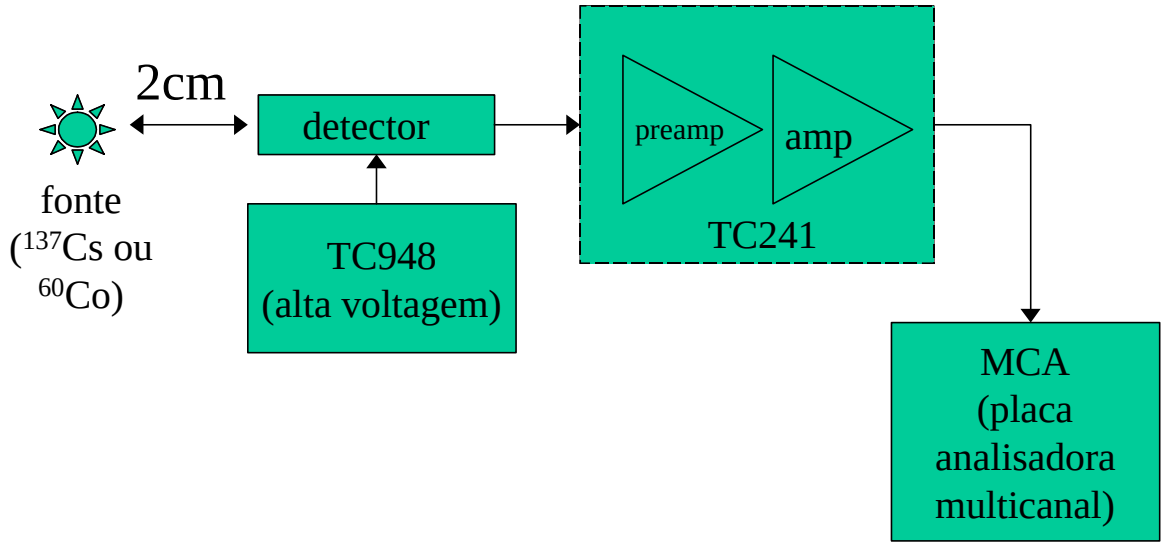

Fig.1. Electronic Block Diagram for Gamma-Ray Spectroscopy System with NaI(Tl) Detector.

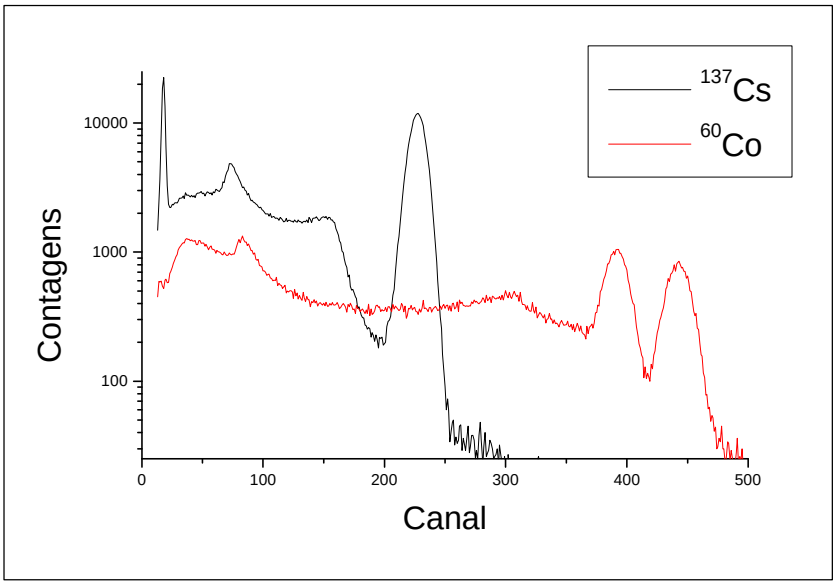

Figure 2 - Spectrum for ^{137}Cs and ^{60}Co.

3. Accumulate the ^{137}Cs spectrum for a time period long enough to determine the peak position. Fig.2 shows a typical ^{137}Cs spectrum that has been plotted.
4. After the ^{137}Cs spectrum has been read out of the multichannel analyzer, erase it and replace the ^{137}Cs source with a ^{60}Co source.
5. Accumulate the spectrum for a period of time long enough for your spectrum to be similar to that in Fig. 2.

3.3 Data Analysis

Plot both the ^{137}Cs and ^{60}Co spectra and fill in items 1, 2, and 3 in Table 1.

From Items 1, 2, and 3 in Table 1 make a plot of energy of the photopeaks versus channel number. Figure 3 shows an example of the calibration plot. If other calibration sources are available, additional data points can be added to Fig. 3.

Table 1

Event	Energy (MeV)	Channel Number
1. 0.662-MeV photopeak	0.662	
2. 1.17-MeV photopeak	1.17	
3. 1.33-MeV photopeek	1.33	
4. Compton edge ^{137}Cs		
5. Backscatter ^{137}Cs		
6. Backscatter ^{60}Co		

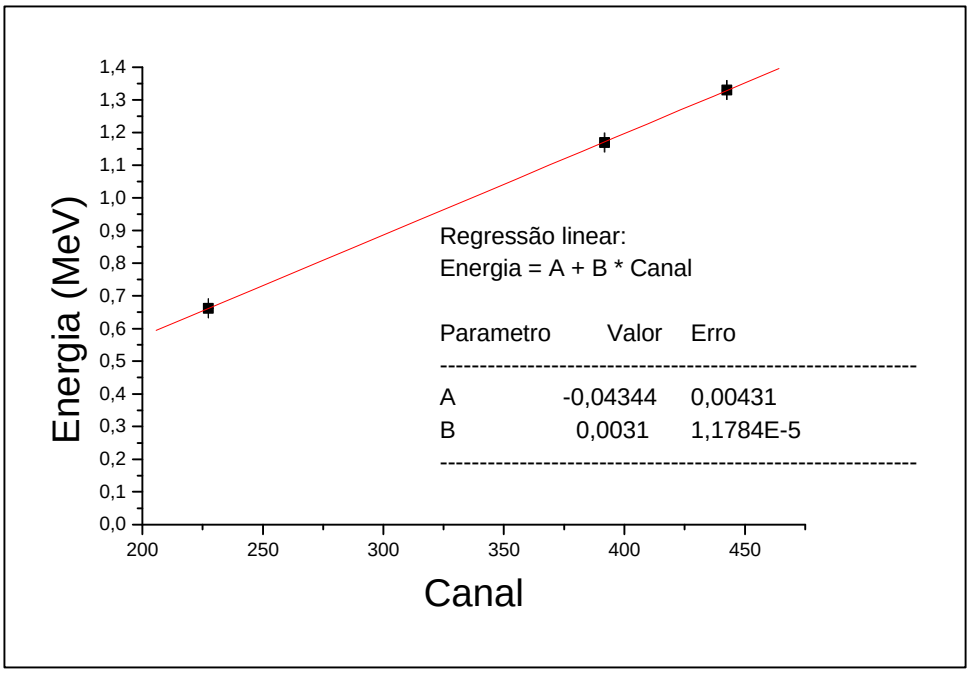

Figure 4 - Energy Calibration Curve for NaI(Tl) Detector.

4. SPECTRUM ANALYSIS OF ^{6O}Co AND ^{137}CS

4.1 Purpose

The purpose of this experiment is to explain some of the portions, other than the photopeaks, that are usually present in a pulse-height spectrum. These are the Compton edge and the backscatter peak.

The Compton interaction is a pure kinematic collision between a gamma photon and what might be termed a free electron in the NaI(Tl) crystal. By this process the incident gamma gives up only part of its energy to the electron. The amount given to the recoil electron (and hence the intensity of the light flash) depends on whether the collision is head-on or glancing. For a head-on collision the gamma imparts the maximum allowable energy for the Compton interaction. The energy of the scattered gamma can be determined by solving the energy and momentum equations for this billiard-ball collision. The solution for these equations in terms of the scattered gamma can be written approximately as

$$E_{g'} \cong \frac{E_g}{1+2E_g\left(1-\cos q\right)} \qquad (1)$$

where

$E_{g'}$ energy of the scattered gamma in MeV,

q the scattering angle for γ'

E_g the incident gamma-ray energy in MeV.

If q =180^o due to a head-on collision in which γ' is scattered directly back, Eq. (1) becomes:

$$E_{g'} \cong \frac{E_g}{1+4E_g}$$

As an example, $E_{g'} = 0.2MeV$ for an incident gamma energy of *1 MeV*. The energy of the recoil electron *(E_e)* for this collision would be *0.80 MeV*, since:

$$E_e = E_g - E_{g'} \qquad (2)$$

Hence the position of the Compton edge, which is the maximum energy that can be imparted to an electron by the Compton interaction, can be calculated by Eq. (2).

4.2 Data Analysis

Calculate the energy of the Compton edge for the 0.662-MeV gammas from ^{137}Cs. Enter this value in Table 1. From your plot and calibration curve, does this calculation agree with your measured value?

Backscattering occurs when gammas make Compton interactions in the material that surrounds the detector. Backscattered gammas from these interactions $(E_{g'})$ make photoelectric interactions in the NaI(Tl) when they enter the crystal. The energy of the backscattered peak can be found by solving Eq. (2).

Solve Eq. (2) for ^{137}Cs and for the 1.33 MeV gammas from ^{60}Co. Fill in the rest of Table1. How do your measured energies compare with the theoretical energies from Eq. (2)? If the backscatter peak is not very pronounced in your spectrum, it can be improved by accumulating a spectrum with a sheet of lead absorber placed slightly to the left of the source.

5. ENERGY RESOLUTION

The resolution of a spectrometer is a measure of its ability to resolve two peaks that are fairly close together in energy. Figure 2 shows the gamma spectrum that was plotted for the ^{137}Cs source. The resolution of the photopeak is found by solving the following equation:

$$R = \frac{dE}{E} x100 \qquad (3)$$

where

R = the resolution in percent,
dE = the full width of the peak at half of the maximum count level (FWHM), measured in number of channels,
E = the channel number at the centroid of the photopeak.

5.1 Data Analysis

Calculate the resolution of the system from your ^{137}Cs spectrum. Record this value for later reference.

6. SPECTRUM ANALYSIS OF ^{208}Tl

6.1 Annihilation Radiation

This process can produce peaks in thespectrum, depending on whether the annihilation, which results from pair production, occurs in the lead or in the NaI(Tl) detector. If the annihilation occurs in the lead and one of the 0.511 MeV gamma pairs interact in the detector, then an extra 0.51 1 MeV peak will appear in the spectrum that is being measured. It should be remembered that this process can only occur for radioactive sources that have gammas in their decay scheme greater than 1.02 MeV.

In the second case, where the incident photon annihilates in the detector, there are, in general, three peaks that can be produced. If the initial gamma has an energy E_γ, the first peak seen in the spectrum corresponds to E_γ. In this case, E_γ annihilates in the detector and both annihilation quanta interact by the photoelectric process before escaping from the detector. We have thus totally absorbed the energy of the incident gamma. A second peak will be seen at E=0.511 MeV. This peak is produced when one of the annihilation quanta is absorbed and the other escapes. In the spectra, this is called the first escape peak. The third peak of energy E= E_γ-1.02 MeV is observed when both annihilation quanta escape from the detector before being absorbed. This peak is called the second escape peak. The probability of seeing the total absorption peak and the two escape peaks depends on the incident gamma energy and the size of the detector. Figure 5 shows a NaI(Tl) spectrum of ^{228}Th and its daughters. In this case E_γ is 2.615 MeV from ^{208}Tl. The single escape peak is 2.104 MeV and double escape occurs at 1.593MeV.

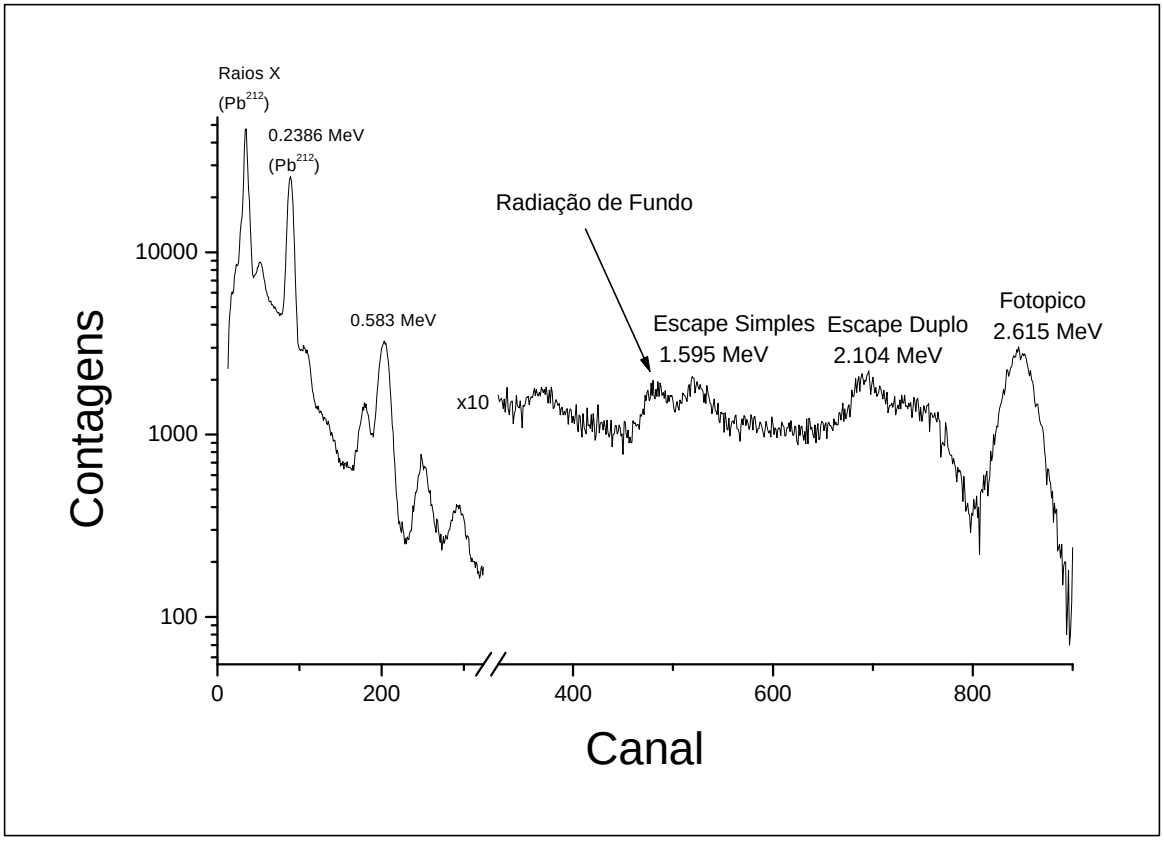

Figure 4. Gamma Ray Pulse Height Spectrum of a ^{228}Th Source. This spectrum shows the single and double escape peaks from the 2.615 MeV gammas.

7. ATENUAÇÃO DE *gs* NA MATÉRIA

Estudo da lei de atenuação de γs em folhas de chumbo de espessuras diversas e determinação do seu coeficiente de absorção (faça várias combinações das espessuras fornecidos).

7.1 Mass Absorption Coefficient

7.1.1 Purpose

The purpose of the experiment is to measure experimentally the mass absorption coefficient in lead for 662 keV gamma rays.

Gammas interact in matter primarily by photoelectric, Compton, or pair production interactions The total-mass absorption coefficient can be measured easily with a gamma-ray spectrometer. In this experiment we will measure the number of gammas that are removed from the photopeak by photoelectric or Compton interactions that occur in a lead absorber placed between the source and the phototube.

From Lambert's law the decrease of intensity of radiation as it passes through an absorber is given by:

$$I = I_0 . e^{-mx} \qquad (4)$$

where

I = intensity after the absorber,
I_0 = intensity before the absorber
μ = total- mass absorption coefficient in cm^2/g
x = density thickness in g/cm^2

The density thickness is the product of the density in g/cm^3 times the thickness in cm.

The half-value layer (HVL) is defined as the density thickness of the absorbing material that will reduce the original intensity by one-half. From Eq. (4):

$$\ln I / I_0 = -mx \qquad (5)$$

If I/I_0 = 0.5 and x = HVL, ln 0.5=-μ(HVL) and hence

$$HVL = 0.693/\mu \qquad (6)$$

In this experiment we will measure μ in lead for the 0.662MeV gammas from ^{137}Cs. The accepted value is 0.105 cm^2/g.

7.1.2 Experimental Procedure

1. Place the ^{137}Cs source about 10 cm from the NaI(Tl) detector and accumulate the spectrum long enough for the sum under the 0.662-MeV peak (Σ_{Cs}-Σ_b) to be at least 6000 counts. Record the live time, read out the multichannel analyzer, and determine (Σ_{Cs}-Σ_b).

2. Erase the multichannel analyze and insert the first piece of lead between the source and the detector. Accumulate the spectrum for the same period of live time as in step 1 above. Read out the multichannel analyzer and determine (Σ_{Cs}-Σ_b).

3. Repeat with additional thicknesses of lead until the count-sum is less than 1000. Fill in the data in Table 2.

Table 2 Data for Mass Absorption Coefficient

Absorber	Absorber Thickness (mg/cm^2)	(Σ_{Cs}-Σ_b)
1	0	
2		
3		
4		
5		
6		

7.1.3 Data Analysis

Using semilog graph paper, plot I vs absorber thickness in mg/cm^2, where I = (Σ_{Cs}-Σ_b)/live time. Determine the HVL from this curve and calculate μ from Eq. (6). How does your value compare with the accepted value of 0.105 cm^2/g ?

(Optional) Repeat the above experiment for aluminum absorbers. The μ for aluminum is 0.074 cm^2/g.