Alpha Particle Measurements with Surface Barrier Detectors
&
Study of the Energy Loss of Alpha Particles in Matter

Discussion

This experiment is designed to show the student how to use surface barrier detectors to study the properties of alpha emitting isotopes. In Experiment #4 which follows this experiment, the energy loss of alphas in thin foils will be studied. The electronic configuration for the two experiments is the same.

Silicon Surface Barrier Charged Particle Detectors

The first thing that the student will realize is that these detectors are extremely easy to use. Tennelec makes detectors that range in size from 25 mm^2 to 2000 mm^2 active area. These detectors are 100% efficient over their active area and can be used to measure a wide range of charged particles. This range includes protons and electrons as low as 20 keV up to fission fragments of energy over 100 MeV. Figure 3.1 shows a pulse height spectrum of scattered protons at 150 keV. On the other hand, fig. 3.2 shows a fission fragment spectrum from ^{252}Cf. The light fission fragment group (the one on the right) has an energy of 103 MeV while the heavy group is 70 MeV. The data analysis with these detectors is extremely simple since they are 100% efficient. For example, in fig. 3.1, if one wished to know the number of scattered protons for the data in the figure, it would only be necessary to integrate under the peak and subtract the estimated background from the sum. These detectors can be thought of as a solid state ionization detector. When a charged particle enters the depletion region of the detector, it loses its energy primarily by making electron hole pairs in the silicon.

For each electron hole pair that is made, the initial charged particle must lose 3.6 eV. In this experiment we will be measuring alpha particles that have an energy of 5.305 MeV. When these alphas enter the detector, 1.47 x 10^6 electron-hole pairs will be produced. The detector is reverse biased and these electron-hole pairs are collected to produce the output pulse of the detector. Since there are a large number of charge carriers produced, the statistical variation in the number collected is small and hence very good resolution is possible. Tennelec can provide detectors with resolutions as low as 12 keV for alphas for the PP series premium partially depleted detectors. The detector recommended for this experiment is a PD series Partially Depleted Detector with 15 keV resolution. This detector is cheaper and is quite adequate for the experiment.

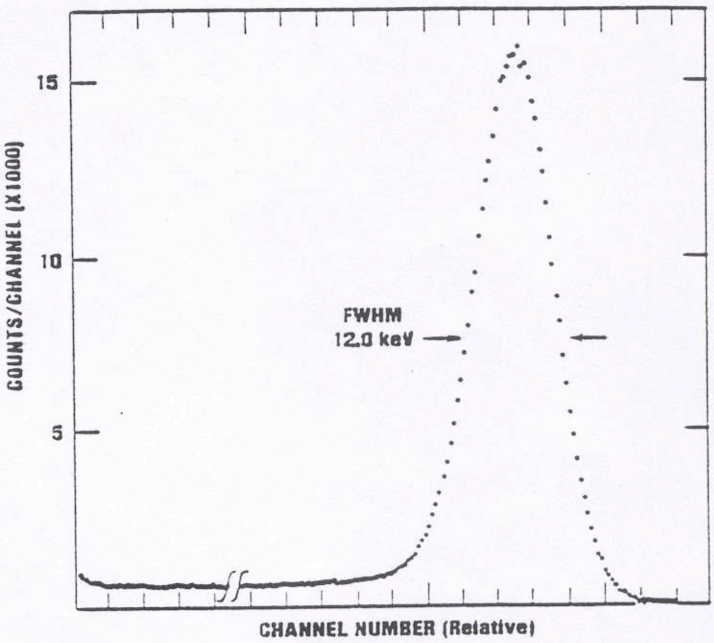


Figure 3.1. Silicon Surface Barrier Detector pulse height spectrum of 150 keV scattered protons from the ^{12}C (p,p) ^{12}C reaction at 30°.

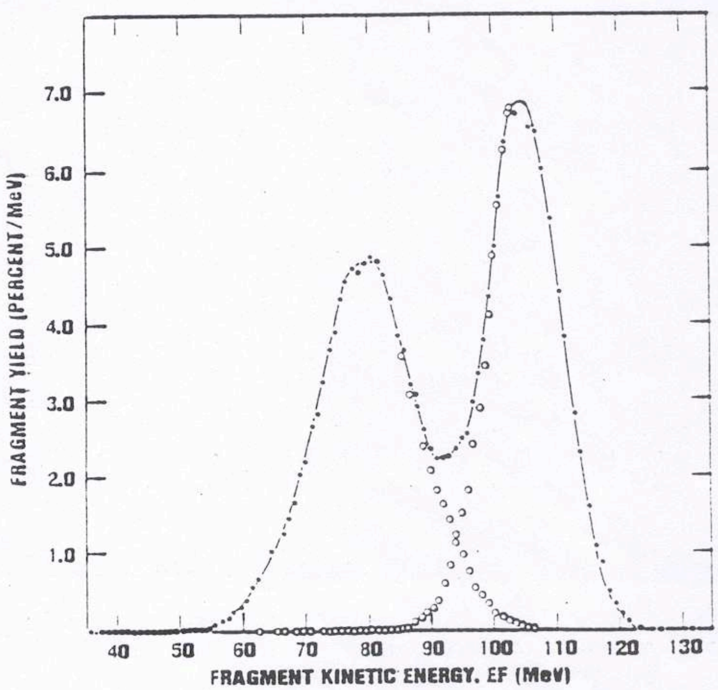


Figure 3.2. Surface Barrier Detector Fission Fragment Spectra from ^{252}Cf (courtesy of Stan Whetstone and the Physical Review Reference 1).

The final parameter necessary to evaluate in selecting a detector is the depletion depth of the detector. In the next experiment, we will study the energy loss and range of charged particles in matter. Alpha particles from radioactive sources have a range of energies from 1.83 MeV for $^{144}N_d$ to 11.65 MeV for ^{212m}Po. Most of the alpha sources that are convenient to use for this experiment have energies around 5.0 MeV. Figure 3.3 shows the theoretical range of five different charged particles in Silicon. From the figure, it can be seen that the 5 MeV alphas that we use for this experiment have a range of approximately 20 microns (μ). These alphas can easily be stopped in any of the partially depleted detectors that Tennelec manufactures since the minimum depletion region of all of these detectors is at least 100 μ. The detector recommended for this experiment is Tennelec model PD-050-100-014-CM. Figure 3.4 explains the significance of this number.

In summary, the detectors are small, easy to use, relatively inexpensive, have excellent resolution, and can be used to measure virtually any charged particle.

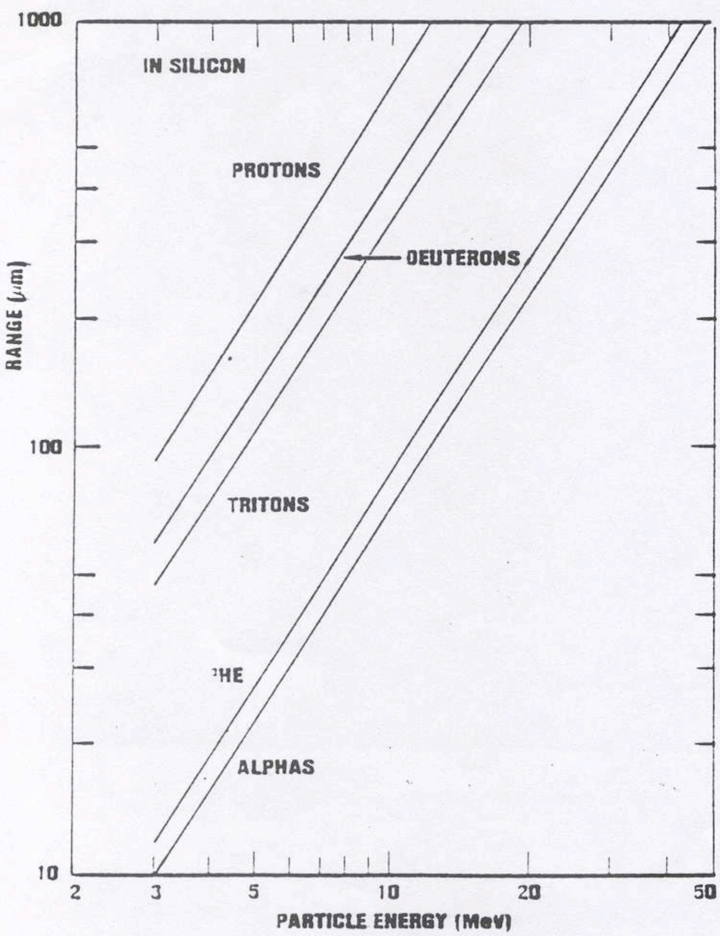


Figure 3.3. Calculations of range vs energy curves for different charged particles in Silicon (from D. J. Skyrme, Ref 2).

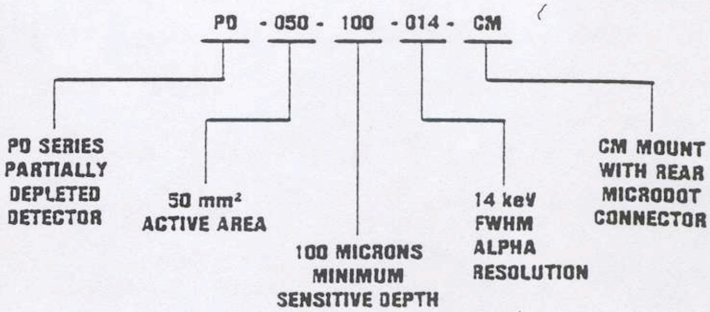


Figure 3.4. Explanation of the nomenclature used to define the model numbers of Tennelec Surface Barrier Detectors.

Health Physics Considerations for Alpha Sources

The alpha sources that are used for this experiment have been either electrodeposited or evaporated onto a metal disk. If you look very carefully, the deposited spot, which is usually about 1 mm in diameter, can be seen in the center of the disk. The spot should never be touched with the fingers because some of the evaporated material might break loose and contaminate your hand and/or the work area. Always handle these sources by holding the edge of the disk. In the case of the ^{210}Po source, the radioactive material is evaporated onto a silver disk. The disk is then completely encapsulated with plastic, except for a small hole on the front surface to emit the 5.31 MeV alphas from the source.

EXPERIMENT 3.1

Energy Calibration with a Pulser for Alpha Spectroscopy

Scope

The electronics shown in fig. 3.5 will be calibrated. An energy versus pulse height curve will be be constructed with the aid of the Pulse generator. The resolution of the system will be determined for alphas from ^{210}Po.

Experimental Procedure

1. Set up the equipment as shown in fig. 3.5. Place the ^{210}Po source in the vacuum chamber approximately 1 cm from the face of the detector. Evacuate the chamber for about 2 minutes. If there are no leaks, the fore pump will run very quietly after this period of time.

2. Set the Bias Supply to positive and adjust its value to the recommended value for the Silicon Surface Barrier Detector, correcting for the voltage drop on the series

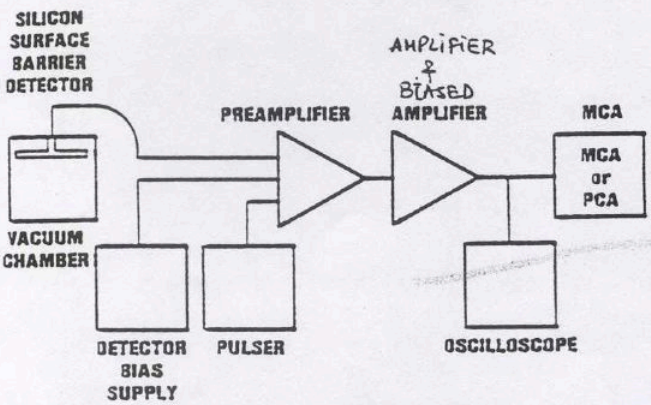


Figure 3.5. Alpha Spectroscopy System with Multichannel Analyzer (MCA).

resistor of the preamplifier as a result of detector leakage current.

Note, whenever you pump down or let the chamber up to air, it is imperative that the Bias supply be turned off. It can be turned on only when the system is under vacuum or at atmospheric pressure. If these procedures are not followed, the detector and the preamp could be damaged.

3. Set the input polarity of the amplifier to positive. The baseline restorer should be set to AUTO. The output from the amplifier to the MCA should be unipolar. Use 1000 channels for the MCA.

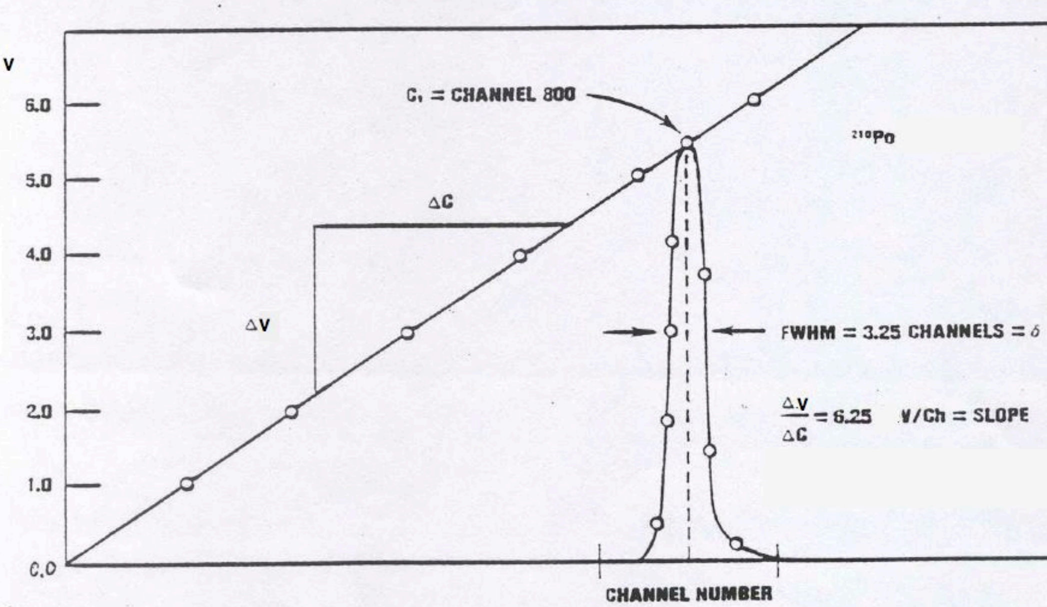
4. Adjust the coarse and fine gain of the amplifier so that the output pulses are about 4V in amplitude. The alphas from ^{210}Po have a discrete energy of 5305 keV. The output of the amplifier will be a single isolated pulse height and easy to observe with the scope.

5. Turn on the MCA or PCA and you will see a single peak that comes in around mid scale. Adjust the gain of the amp such that the ^{210}Po alphas fall approximately in channel 800.

6. Accumulate a spectrum for a time period long enough to have 500 counts in the peak channel. This should take only a few minutes. Use the cursor of the MCA to determine the centroid channel of the peak. If your MCA has a centroid finding program, the centroid can easily and accurately be found by using this program. Once this centroid channel is found, it should be labeled C_1.

7. Turn on the relay of the pulse generator. Set its polarity to negative. The (C) output of the pulser should be fed into the preamp.. Set the pulse height dial at $^{531}/_{1000}$. The pulse height dial is a ten-turn potentiometer. Each turn corresponds to 100 divisions. Full scale on the dial is therefore 1000 divisions. $^{531}/_{1000}$ is 53% of full scale. Now adjust the attenuation switches and the CAL screwdriver adjustment until the pulser peak falls at exactly C_1 in the MCA. You have now calibrated the pulser pulse height dial so that $^{531}/_{1000}$ divisions is equal to 5305 keV. Each division is then 10 keV. It is now quite easy to generate a 4 MeV pulse by setting the pulse height dial at $^{400}/_{1000}$, etc.

8. Erase the MCA and set the pulse height dial on the pulser at $^{100}/_{1000}$ (1 MeV) and accumulate for a period of time (about 1.5 minutes) long enough to determine the centroid of the peak. Repeat for the other pulse height settings in Table 3.1. Fill in the rest of Table 3.1.



SUGESTÃO:
Use o Bias Amplif
para obter uma
calibração de
~3 keV/canal

Figure 3.6. Calibration curve for the Pulse Generator showing a ^{210}Po spectra and the Resolution of the detector.

Table 3.1 Pulser Calibration Data

Pulse Height Dial Setting	... ...	... ...
100/1000		
200/1000		
300/1000		
400/1000		
500/1000		
600/1000		

Exercise A From the data in Table 3.1, make a plot of voltage versus channel number. Figure 3.6 shows a typical calibration curve for this experiment.

EXPERIMENT 3.2

Using the Calibration Curve to Determine the Energy of the Unknown Alpha Source

Scope

The calibration obtained in Experiment 3.1 will be used to accurately determine the alpha energies of one or more unknown sources.

Experimental Procedure

1. Turn off the Bias voltage and slowly leak the vacuum chamber up to atmospheric pressure. This should take about 1 minute. Replace the ^{210}Po source with the unknown source that is supplied by the instructor. Pump the system back down and then turn on the Bias supply to its recommended value.

2. Accumulate a spectrum in the MCA until reasonable statistics are acquired in all of the peaks of interest for the unknown.

3. Use the cursor of the MCA or one of the programs stored in the MCA to find the centroid and the number of channels across the FWHM for the unknown source.

4. Repeat steps 1-3 for the other unknowns that the instructor may wish to have analyzed.

Exercise A Determine the energy or energies of the alpha peaks in your unknown spectrum from the calibration curve.

Energy loss of α particles

For the measurements outlined in this experiment the dE/dx of alphas can be written as follows[6]:

$$\frac{dE}{dx} = \frac{2\pi Z_1^2 e^4 N Z}{M_o^2} \ln\left(\frac{2M_o^2 Q_{max} - 2\beta^2}{I^2(1-\beta^2)}\right) \qquad (1)$$

where

- Z_1 The atomic number of the alpha
- e The electronic charge (esu)
- M_o = rest mass of the electron (g)
- v = velocity of the alpha cm/s
- β = v/c
- NZ = number of electrons/cm^3
- Q_{max} = maximum kinematic transfer from an electron to an alpha particle (ergs)
- I = mean ionization potential (ergs)
- E = energy of the incident particle

The logarithmic term in eq. (1) varies slowly with energy and hence it is approximately correct to write:

$$dE/dx = \frac{\text{constant}}{E} \qquad (2)$$

For a thin foil:

$$E = \left(\frac{dE}{dx}\right) \Delta X \qquad (3)$$

However, from fig. 4.2 it is obvious that for a fairly thick foil there is need to integrate the dE/dx expression over the thickness of the foil since the dE/dx upon entry will be different than its value for the last row of atoms in the foil, the true energy loss can be found as follows:

$$\Delta E = \int \left(\frac{dE}{dx}\right) dx \qquad (4)$$

In eq. (4), the analytic expression for dE/dx is used. It is seen from the experiment that the range curves are perhaps the easiest and best way to get the theoretical value for energy loss. Rearranging eq. (4) and integrating from the incident alpha energy E_0 to zero gives:

$$\text{Range} = \int_{E_0}^{0} \frac{dE}{\left(\frac{dE}{dx}\right)} \qquad (5)$$

In this experiment, both the (dE/dx) and range method of calculating the energy loss of alphas in a variety of materials will be used.

Table 4.1 shows the integrated ranges for the foils that will be studied in this report. These semiempherical values were taken from ref. 7.

Table 4.1 Range of Alpha Particles Versus Energy For Al, Ni, Cu, Ag, Ag and Mylar (Taken from Reference 7)

Range in Units of mg/cm^2

Energy (MeV)	Al	Ag	Au	Cu	N	O	Ne	Mylar	He
.050	.142	.371	.746	.479	.123	.132	.149	.097	.081
.080	.190	.487	.976	.525	.170	.181	.204	.133	.113
.128	.252	.634	1.269	.605	.232	.247	.277	.180	.158
.201	.327	.812	1.620	.726	.312	.330	.367	.238	.219
.400	.497	1.199	2.362	.968	.490	.513	.560	.366	.364
.500	.574	1.369	2.675	1.085	.563	.588	.639	.421	.425
.640	.680	1.597	3.086	1.300	.654	.684	.739	.493	.500
.800	.802	1.854	3.539	1.440	.750	.783	.844	.570	.579
1.000	.959	2.178	4.099	1.688	.863	.900	.969	.665	.671
1.60	1.475	3.209	5.825	2.503	1.193	1.246	1.346	.959	.937
2.00	1.86	3.955	7.039	3.107	1.428	1.493	1.620	1.174	1.121
2.401	2.283	4.758	8.323	3.758	1.687	1.765	1.925	1.412	1.320
2.80	2.745	5.622	9.687	4.455	1.979	2.073	2.269	1.678	1.538
3.20	3.244	6.544	11.126	5.196	2.308	2.418	2.655	1.973	1.778
4.000	4.349	8.549	14.205	6.808	3.079	3.227	3.564	2.658	2.331
5.00	5.920	11.339	18.411	9.057	4.236	4.444	4.931	3.682	3.156
6.40	8.460	15.759	24.929	12.610	6.189	6.487	7.222	5.422	4.556
8.00	11.835	21.512	33.237	17.280	8.851	9.277	10.321	7.829	6.504

Table 4.2 shows the stopping power of alpha particles as a function of energy for various foils.

Table 4.2 dE/dx in MeV/mg/cm² for Various Materials (Taken from Reference 7)

Energy (MeV)	Al	Ag	Au	Cu	N	O	Ne	Mylar	He
.050	.532	.223	.112	.311	.564	.530	.471	.713	.851
.080	.673	.282	.141	.401	.684	.644	.576	.889	.989
.128	.852	.358	.180	.670	.817	.777	.710	1.107	1.102
.201	1.040	.444	.226	.643	.956	.930	.865	1.346	1.211
.400	1.28	.575	.307	.764	1.303	1.262	1.201	1.757	1.572
.500	1.317	.604	.331	.780	1.442	1.389	1.327	1.888	1.745
.640	1.323	.622	.349	.781	1.604	1.546	1.466	2.021	1.955
.800	1.299	.622	.357	.770	1.734	1.665	1.574	2.096	2.117
1.000	1.248	.610	.357	.740	1.816	1.748	1.632	2.114	2.239
1.60	1.086	.555	.338	.660	1.776	1.688	1.529	1.947	2.237
2.00	.996	.520	.322	.630	1.640	1.561	1.396	1.786	2.112
2.401	.904	.480	.302	.580	1.458	1.385	1.238	1.593	1.926
2.80	.832	.448	.285	.550	1.292	1.227	1.098	1.427	1.756
3.20	.773	.422	.271	.520	1.152	1.098	.982	1.287	1.593
4.00	.682	.380	.250	.460	.949	.900	.802	1.073	1.329
5.00	.598	.340	.228	.410	.792	.756	.672	.895	1.113
6.40	.512	.297	.204	.360	.655	.626	.561	.730	.907
8.00	.442	.262	.183	.320	.556	.530	.479	.610	.750

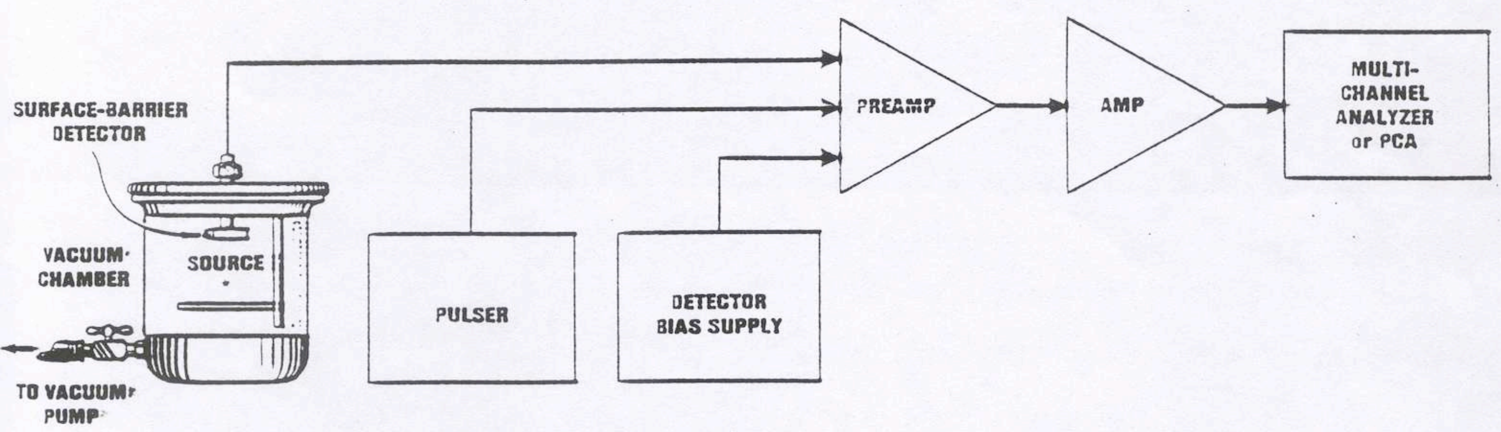


Figure 4.3. Electronics for dE/dx Experiment.

EXPERIMENT 4.1

Energy Loss of Alpha Particles in Thin Metallic Foils

Experimental Procedure

(dE/dx for Copper)

1. Set up the equipment as shown in fig. 4.3. Use the ^{210}Po source and the pulse generator to construct an energy versus channel calibration curve. The gain of the amplifier should be set such that the 5.305MeV alphas from ^{210}Po are approximately in channel 800. Calculate the slope of the calibration curve in keV/channel.

2. Turn off the bias and vent the system to air. Place the thinnest copper foil between the ^{210}Po source and the detector, and pump the system back down. Return the bias to its recommended value and determine the position of the alpha peak. From the calibration curve, determine its energy (E_f) and record this value in Table 4.3.

3. Turn off the bias and slowly let the system up to air. Remove the copper foil and replace it at the same position with the next thickest foil. Determine the energy of the ^{210}Po alphas through this foil and record the measured value in Table 4.3.

4. Repeat for the rest of the copper foils in the set. Figure 4.4 shows a typical superposition of several of the above measurements on the same graph.

5. This experiment may also be done for any of the other foils that the instructor may provide (see Tables 4.1 and 4.2 or ref. 7). Figure 4.4 shows a typical pulse height spectrum of the ^{210}Po alphas before going through a foil. This experiment could have been done with any of the alpha sources that were shown in Experiment 3. Figure 4.5 shows a spectrum of another alpha source which is suitable for this experiment ^{234}U.

NOTA: Use sempre 5.305 MeV na análise

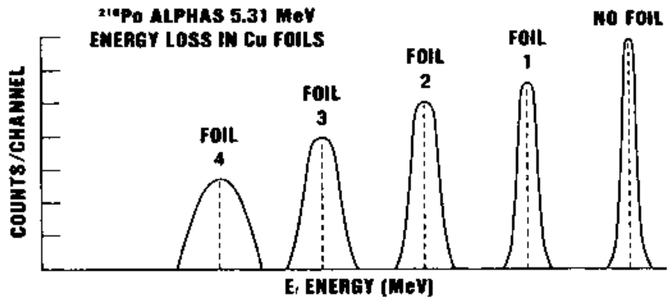


Figure 4.4. Composite Spectra of the Energy Loss of ^{210}Po Alphas in Thin Copper Foils.

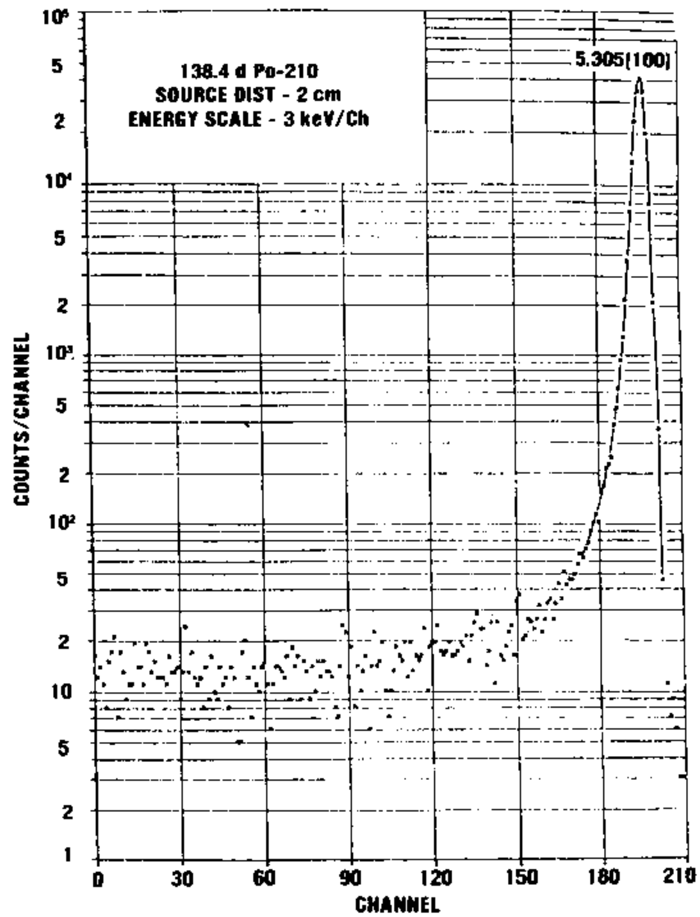


Figure 4.5. Alpha Particle Pulse Height Spectrum of ^{210}Po (No Foil).

Table 4.3 Comparison of the Experimental and Theoretical Value of Energy Loss of ^{210}Po Alphas in Thin Copper Foils

No.	Foil Thickness mg/cm²	Channel	Final Energy E_f MeV	ΔE_m Measured MeV	ΔE Theory Range Method	ΔE Theory (dE/dx) average	ΔE Theory (dE/dx) por troço
1							
2							
3							
4							
5							

Exercise A Calculation of the theoretical value for the energy loss E_{Th} can be done by two methods. These are the range method (Exercise a) and the$(dE/dx)_{av}$ method (Exercise b).

As mentioned in the preliminary discussion eq. (5), the range of an alpha particle can be determined by integrating the (dE/dx) of the alpha over its path length from E_o, the initial energy, to zero, the final energy. Figure 4.7 shows the range that results from this integral for incident alphas between 0.10 and 6 MeV. From this curve it can be seen that the range of an alpha from ^{210}Po that has an energy of 5.31 MeV corresponds to a range in copper of 9.3 mg/cm^2. Assume that the first copper foil used was 2.0 mg/cm^2. Figure 4.7 can be used to find the final energy E_f of the alpha after it has passed through the foil. This is done by subtracting the foil thickness from the 9.3 mg/cm^2 and then reading the energy E_f of the alpha from fig. 4.7. Example:

$$R_f = (9.3 - 2.0) \text{ mg/cm}^2 = 7.3 \text{ mg/cm}^2 \qquad (6)$$

From fig. 4.7, the energy E_f of an alpha whose range is 7.3 mg/cm^2 is 4.2 MeV. Therefore, E_f, the energy that the alpha gives ΔE_{Th} = 5.30 MeV — 4.2 MeV = 1.1 MeV. This value would then be entered into Table 4.3 as ΔE for that foil.

Compute ΔE_{Th} for all of the copper foils that the instructor provides. Repeat these calculations for any other foils that the instructor may provide.

Exercise B The theoretical (dE/dx) may also be determined by using the average (dE/dx) method.

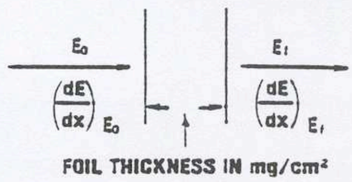


Figure 4.8. Illustration showing an alpha of energy E_o entering a foil and leaving with an energy E_f.

The value of $(dE/dx)_{E0}$ at the incident energy can be found from Table 4.2. When the alpha leaves the foil, its energy is E_f and the $(dE/dx)_{Ef}$ can also be found from Table 4.2. Since the foil is fairly thin, it can be assumed the (dE/dx) change across the foils is approximately linear. It is thus possible to write:

$$\left(\frac{dE}{dx}\right)_{Av} = \frac{\left(\frac{dE}{dx}\right)_{E0} + \left(\frac{dE}{dx}\right)_{Ef}}{2} \qquad (7)$$

The theoretical energy loss using $(dE/dx)_{Av}$ is then given by:

$$(\Delta E)_{Th} = \left(\frac{dE}{dx}\right)_{Av} \cdot \Delta X \qquad (8)$$

Note, that since the units of dE/dx are in MeV/mg/cm^2 and the foil thickness ΔX is in mg/cm^2, the resultant product in eq. (8) has units of MeV.

Use eq. (8) to calculate $(\Delta E)_{Th}$ for all of the foils that are provided for this experiment. Record these values in Table 4.3.

Exercise C The last column in Table 4.3 is the % difference. Since the ΔE_{Th} obtained by the range method (exercise a) should be more accurate, use it as the accepted value. If the student is very careful with the measurements and accurately reads the graphs, tables, and calibration curves, these % differences should be less than 10%.

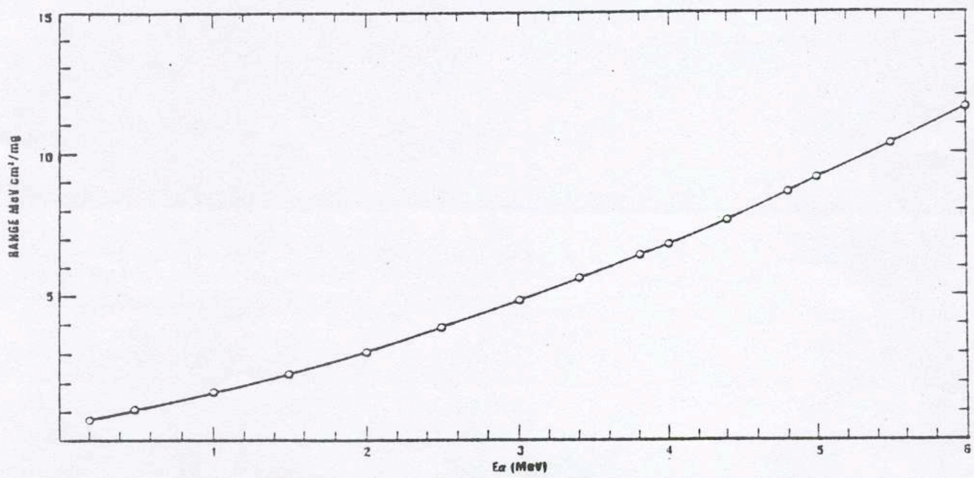


Figure 4.7. Energy vs Range for Alphas in Copper (taken from ref. 7). Note, the student should plot this range curve on graph paper from the data in Table 4.1 The range numbers can then be accurately read from the graph.