Experiment #5: Alpha Particle Slowing Down and Energy Straggling in Gas

References:
Lecture Notes
LABView Tutorial
G.F. Knoll. Radiation Detection and Measurement
N. Tsoufaniides, Measurement and Detection of Radiation
K.S. Krane, Introductory Nuclear Physics

Objective:
This experiment is designed to quantify in the laboratory the concepts of specific energy loss and energy straggling of alpha particles as they slow down both as a function of target gas pressure and source-detector separation. Some insights on real-world alpha sources, connected to energy loss in the windows material will be gained in the preliminary calibration part. In addition, the experiment will illustrate the use of LABView graphical programming software for both controlling aspects of the experiment and acquiring some of the data.

Introduction:
The specific energy loss of α particles can be described by means of the Bethe formula:

\[
\frac{dE}{dx} = \frac{4\pi e^2}{m_0 v^2} \rho_{\text{part}} N Z_{\text{med}} \left[ \ln \frac{2 m_0 v^2}{l} - \ln \left( 1 - \frac{v^2}{c^2} \right) - \frac{v^2}{c^2} \right]
\]  \hspace{1cm} (1)

where \( e_{\text{par}} \) is the incident particle’s charge, \( v \) its velocity, \( m_0 \) the electron rest mass, \( Z_{\text{med}} \) the atomic number of the absorber and \( N \) its number density. From here it is seen that the energy loss \( dE \) depends, among other factors, on the absorber’s density \( (N) \) and the distance traveled \( (dx) \) from the source.

The statistical nature of the interaction precludes a deterministic calculation of alpha particle range: the energy of an α particle at some distance from the source can not be entirely described by a single value but must be treated in terms of a distribution. The width of this distribution is a measure of ‘energy straggling’ and the mean energy is a function of the distance traveled. A second interesting feature is that the distribution’s skewedness is affected by the distance as well. While at the beginning of the particle’s path the distribution is rather peaked, at intermediate distances a long tail appears to the left of the peak and then disappears for long paths (high penetrations).
The alpha particle's behavior is also influenced by very thin absorbers, such as in a detector window. This should be kept in mind by the experimenter, especially when it comes to the choice of a detector or the preparation of sources. A real-life example is the heart of the preliminary energy calibration of the apparatus.

Dependence on pressure, distance, location and shape of the spectra are investigated in the main part of this experiment.

**Equipment:**

The equipment used for this experiment includes a passivated implanted planar silicon (PIPS) detector with the accompanying counting electronics and power supply; a chamber, pressurized by a pump and monitored by analogue and digital manometers; and a pressure regulator, driven by a computer which also provides the data acquisition and analysis system.

Also, two $^{241}$Am sources, a $^{238}$Pu source and a $^{244}$Cm source will be used.

**Procedure:**

This experiment will be done in two parts. First, you will carry out the steps necessary to calibrate the alpha detector. Then you will go on to measure energy straggling as a function of distance and pressure.

1. **Energy calibration** The first step in this experiment is to obtain an energy calibration for the PIPS detector, amplifier and MCA system used to acquire the experimental data. The calibration will be used to relate particle energy to the MCA channel number, in a relationship of the form $E=mN+q$, where $E$ is the particle energy and $N$ is the channel number. You need to choose the most suitable source for the calibration among the four sources available.

   - Turn on the NIM crate housing the spectroscopy amplifier for this experiment. The following amplifier settings are suggested: coarse gain 16, fine gain 5.00, positive polarity. Turn the high voltage power supply on and apply +40V to the detector via the preamplifier.
     
     **CAUTION:** do not exceed +40 volt bias on this detector! You should check the output voltage of the preamplifier with a voltmeter.

   - The computer is used to obtain the alpha-particle energy spectra using a Canberra AccuSpec MCA, which runs under DOS. Launch Windows 95, Run the MCA program by switching to DOS (Start >> Programs >> LABView icon); at the DOS prompt, type the following commands:

     ```
     c:\windows> cd \mca
     c:\mca> alctrl
     c:\mca> mca
     ```

   - In this part of the experiment, the pump is connected directly to the chamber to save time. **CAUTION:** when you are modifying the
piping and/or valve arrangement never obstruct the pump inlet!
You may also wish to connect the analogue manometer. In the
following four trials write down any data quantifying deviations from
what you might expect and try to give an explanation of what
happens. Include this in the write up.

- **First Source** Place the green $^{241}$Am source close to the detector (you
can fix it to the detector with a piece of tape). Once the source is
mounted, carefully close the cylindrical Plexiglas chamber so that the
Viton o-rings are just resting on the edge of the cylinder and start the
pump to evacuate it. If the pressure is not dropping, there is probably
a leak. Check the seal between the o-rings and the surfaces of the
chamber. When the pressure reaches ~15 mm Hg, switch to the
MCA and collect a spectrum until you have sufficient statistics to
define the channel number where the peak occurs and record it.
Americium-241 has two main alpha decay channels (See Table 1).
Can you see them?

- **Second Source** Return the chamber to atmospheric pressure and
place the metallic $^{241}$Am source on the detector. Before evacuating
the chamber collect a spectrum. Can you see the expected peaks?
Now evacuate the chamber and collect a new spectrum. What
conclusions can you draw?

- **Third Source** Place the $^{239}$Pu source in the chamber, evacuate it and
collect a spectrum. How many peaks do you see? Are the energies
what you expect (See Table 1)?

- **Fourth Source** Ask your TA to place the $^{244}$Cm alpha particle source
near the detector as you did for the other sources and take a
measurement. (This is an intense source (about 1 mCi) sufficient to
provide good count rates later during the experiment.) Describe the
quality of data collected and explain any anomalies. Now have your
TA place the source on the movable tray and evacuate the chamber.
Cover the chamber with the cardboard box. What is purpose of the
box? Are the energies the energies expected (See Table 1)?

- Which source should we use for calibration? Is the detector window
responsible for differences in spectra quality and resolution between
the two americium sources?

- Given the good linearity of the device, you can calibrate the detector
setting the energy of the first channel to zero and the main peak of
the isotope you chose to its energy. In other words, we assume that
$q=0$ and the line passes through the origin. Details for calibrating the
MCA are on pages 6-11 through 6-13 of the Canberra AccuSpec
User’s manual.
<table>
<thead>
<tr>
<th>Isotope</th>
<th>Decay energy (MeV)</th>
<th>Branching ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{239}\text{Pu}$</td>
<td>5.156</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>5.143</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>5.105</td>
<td>12</td>
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<tr>
<td>$^{241}\text{Am}$</td>
<td>5.486</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>5.433</td>
<td>13</td>
</tr>
<tr>
<td>$^{244}\text{Cm}$</td>
<td>5.806</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>5.763</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 1 Alpha Decay Data

2. **Energy Straggling** To study the attenuation of alpha particles in air we need a more accurate method to measure and control the chamber pressure. This is achieved in this experiment with a computer controlled system run by LABView, which runs under Windows95.

- Turn the knob to place the $^{244}\text{Cm}$ source at 10 cm from the detector. Evacuate the chamber and connect the pump to the pressure controller and this to the chamber. The pressure controller exhaust must remain free.

- Run the pressure control VI as follows: launch LABView (Start >> Programs>> LABView icon); from the file >> open menu, double click on 22-09.vi, and run the VI by clicking on the run button. You can switch between LABView and the MCA program by using the Alt + Tab key stroke combination.

- In the LABView front panel, set the pressure to 15 mm Hg (slider and green box in the VI front panel) and wait until the chamber has reached this pressure according to the baratron pressure sensor (red box). (This may take 10 minutes). Meanwhile, ask the TA to help you check the voltages in the circuits and how these are controlled by LABView.

- Once the chamber has reached its minimum value, take an energy spectrum. **Check the peak energy using your calibration, does it correspond to the full energy of the decay? If there is any energy loss, does the amount make sense given the limited accuracy of the baratron pressure sensor?** Take 4 or 5 spectra with different detector / source separation distances.

Repeat these measurements to collect a series of spectra at increasing pressures, for each spectrum record the location of the radiation peak and also the width of the peak. **In your analysis, compare the energy loss at each pressure and the straggling at each pressure with those predicted by theory.**

Choose a pressure and distance where the particles have lost on
average half of their original energy. Then, take a measurement with
the pressure at half the earlier value and the distance twice the earlier
value in order to confirm that charged particle slowing depends on the
product of density x thickness of the gas.

Write-Up: In your report, include a printout of the VI used to control the chamber
pressure and a brief explanation of its operations. In addition include a
summary of your data, that lists the peak channel number, the corresponding
energy width of the measured spectrum for each chamber pressure and
source-detector separation. Compare the energy loss in each case with the
predicted value from the Bethe-Bloch formula. All results should have an
uncertainty: since you will be dealing with peaks, include their FWHM in
energy and the resolution (FWHM / central peak).

Include a section describing the effect of windows on the sources and
improvements to make to this experiment.