# RANGE OF ALPHA PARTICLES

The range of a charged particle in an absorber provides a measure of its energy.  In this experiment, the range in air, and energy, of the alpha particles emitted from $^{241}$Am will be determined using a solid-state detector in a chamber in which the air pressure can be varied.  Also, a diffusion cloud chamber will be used to observe the paths of various types of ionizing radiation.

**Theory:**

A heavy charged particle, such as an alpha particle, has a fairly definite range in a gas, liquid, or solid.  The particle loses energy primarily by the excitation and ionization of atoms in its path.  The energy loss occurs in a large number of small increments.  The alpha particle has such a large momentum that its direction is not changed appreciably during the slowing processes.  Eventually it loses all its kinetic energy and comes to rest.  The distance traversed is called the range, and depends on the energy of the alpha particle, the atom density in the material traversed, and the atomic number and average ionization potential of the atoms comprising this material.  A slow (low energy) alpha particle loses more energy by ionizing atoms than a fast (high energy) alpha particle, since the slower particle spends a longer time in an atom, and thus there is a greater probability that an electronic transition will occur in the atom.  This effect can be observed in the ionization along the path of a single alpha particle;  the number of ions produced per unit distance is small at the beginning of the path, rises to a maximum near the end of the path, and then falls sharply to zero when the alpha particle becomes too slow for any further ionization (the end point of the range).  A plot of the specific ionization (number of ions formed per unit distance of beam path) versus distance from the alpha particle source for a beam of alpha particles is called a Bragg curve, and based on the above discussion should have the shape shown in Figure 1.
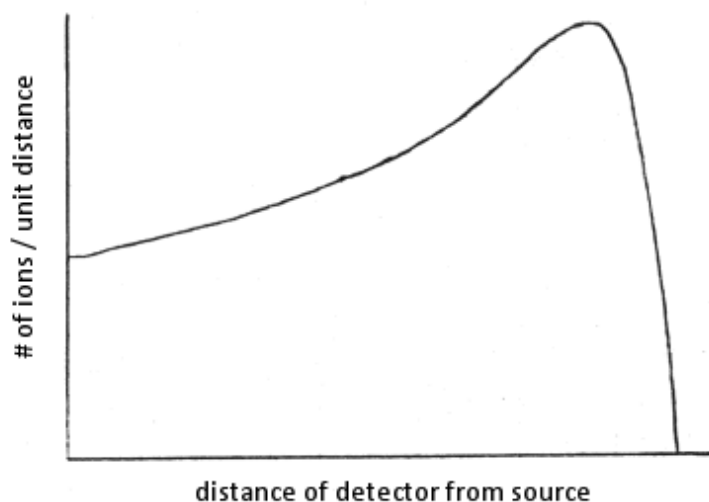


**Figure 1**

Since the energy loss of the alpha particle per ion formed is nearly constant, the specific ionization is proportional to the rate of the alpha particle energy loss, $-dE/dx$, and so a plot of alpha particle energy loss per unit distance versus distance from the source should have the same shape as the Bragg curve of Figure 1.

The two types of measurements that will be used to determine the alpha particle range in this experiment are the number of alpha particles detected as a function of distance from the source, and the residual alpha particle energy as a function of distance from the source. Typical plots of these data, for the region near the alpha particle range, are shown in Figure 2.
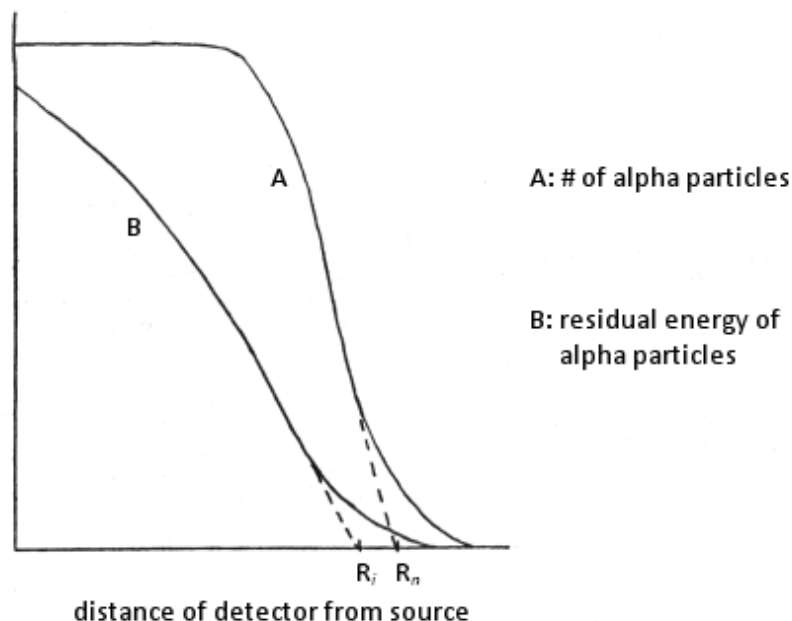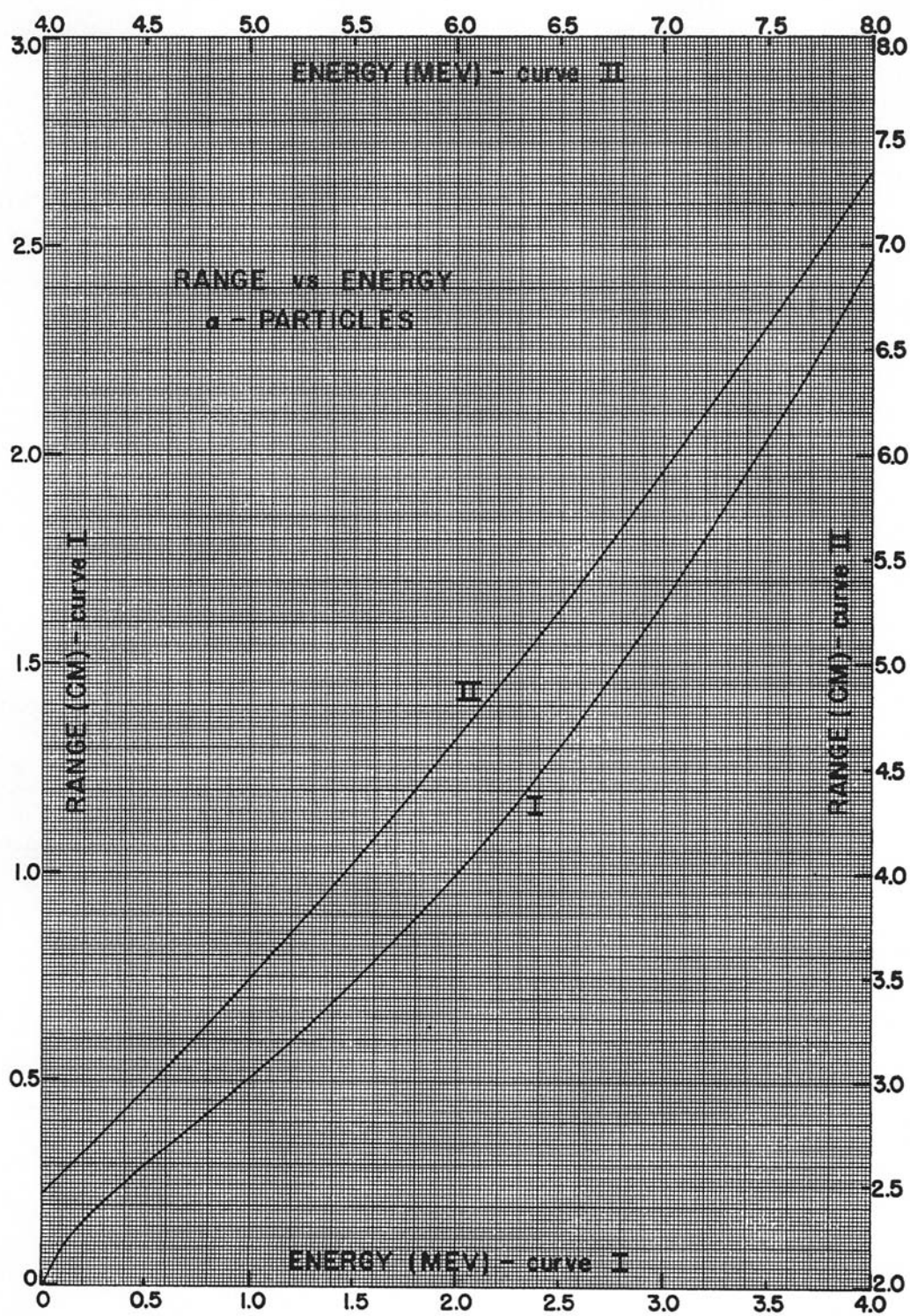


A: # of alpha particles

B: residual energy of alpha particles

$R_i$   $R_n$

distance of detector from source

**Figure 2**

Note that both curves exhibit a 'tail' near the range. This effect is called straggling. Since some alpha particles hit more and others hit less than the average number of molecules in passing through the absorber, the actual distance from the source at which their energy is completely expended is somewhat different for different particles. Because of straggling, the actual range of an alpha particle of well-defined energy is not definite. To avoid this indefiniteness, the curves are extrapolated as shown in Figure 2. Besides the statistical straggling discussed above, straggling effects can be caused by varying energy losses in the source (source straggling), by departure of the beam from parallelism (angular straggling), and by characteristics of the detection and recording equipment (instrument straggling).

Published data and theoretical curves for alpha particle ranges are usually in terms of the average range versus alpha particle energy for air at 15 °C and 76 cm Hg. The average range, $R_{ave}$ is obtained from the number-distance extrapolated range, $R_n$, and the energy-distance extrapolated range, $R_i$, by subtracting 0.06 cm and 0.03 cm respectively, for the energy of alpha particle used in this experiment. Note that this correction is probably insignificant within the accuracy of this experiment. Figure 3 shows the theoretical and experimentally verified range-energy relation for alpha particles in standard air (15 °C, 76 cm Hg) for energies from 0 to 8.0 MeV.

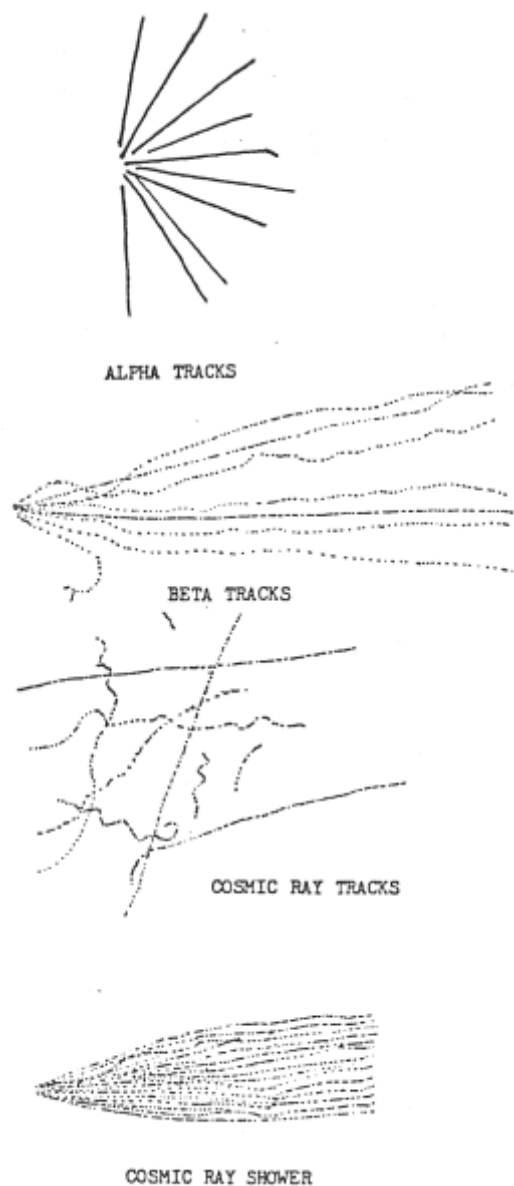**Range-energy relation of alpha particles in air of 15°C and 76 cm**
**Figure 3**

**Apparatus:**

Diffusion Cloud Chamber

    The diffusion chamber is probably the easiest method of observing the paths of ionizing particles. The theory of its operation is briefly as follows: in a region of super-saturated vapour, small droplets will condense on the ions formed by the passage of ionizing particles (alpha and

beta particles) through the region. The super-saturated region is formed by establishing a steep temperature gradient from top to bottom of the chamber, and by maintaining a vapour source at the top of the chamber. A diffusion of vapour from top to bottom occurs, and there will exist a region of super-saturation. The vapour source is methyl alcohol poured into the bottom of the chamber and absorbed into paper placed around the outer wall of the chamber. The temperature gradient is established by placing the bottom of the chamber in contact with dry ice. Gamma rays and cosmic rays can be observed due to their interaction with the gas in the chamber to produce electrons which give evidence of their presence by short, crooked tracks. The chamber is illuminated by a horizontal beam of light to facilitate viewing of the droplet tracks.

ALPHA TRACKS

BETA TRACKS

COSMIC RAY TRACKS

COSMIC RAY SHOWER

Alpha particles leave short, dense tracks ranging up to about 4 cm in length. They may be straight or have a hook or curve at the far end. Alpha tracks may also be seen which do not originate at a radioactive source or which occur when no radioactive source is in the chamber. These 'background' alpha particles originate from the decay of $^{222}$Rn gas in the air.

Beta particles (electrons) leave long thin faint tracks that traverse the chamber from the source to the wall. Some tracks are fairly straight and others are curved or crooked. The tracks appear as finely dotted lines.

The presence of cosmic rays and gamma rays can be detected by observing the tracks left by the mesons and electrons produced following collisions between the cosmic rays and gamma rays and atoms in the chamber. The tracks are long, thin, and faint and may enter the chamber at any angle. The tracks are visible whether or not there are sources in the chamber.

Occasionally a cosmic ray shower may be observed. This appears as a large number of tracks arising at the same point at the wall or near the top of the chamber. The shower results from the collision of a high energy cosmic particle with an atom. This collision frees secondary particles which in turn collide with other atoms, releasing additional particles. This series of collisions results in a large number of tracks seeming to form simultaneously.

The Range of Alpha Experiment

    Figure 4 shows a block diagram and photograph of the equipment used to determine the number-distance and energy-distance curves for the alpha particles emitted by $^{241}$Am.
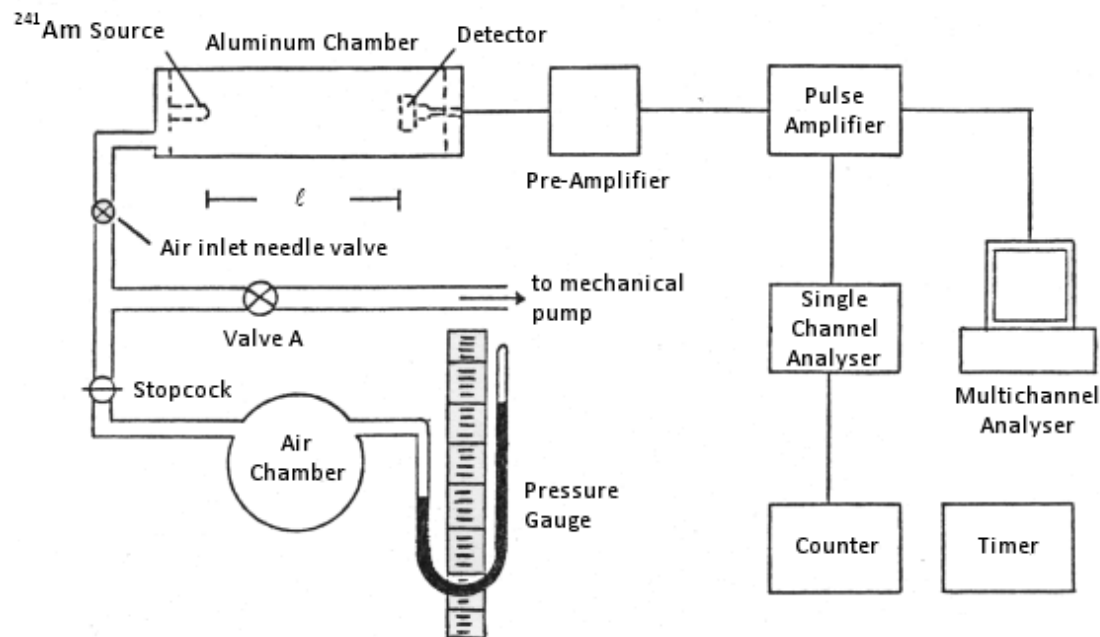


**Figure 4**

    The *actual* distance between the source and detector is *fixed* (7.8 cm), the variable parameter being the air pressure in the aluminum chamber containing the source and detector.  From the

ideal gas law, an *effective* source-detector separation, $d$, in standard air (15 °C, 76 cm Hg) can be determined from the *fixed* source-detector distance, $\ell$, the *actual* air pressure between source and detector, $p$, and the room temperature, $T$. The actual conditions in the chamber yield a certain average number of air molecules, $n_{act}$, between the source and detector. Let $n_{eff}$ be the average number of air molecules between source and detector when the chamber contains standard air (15 °C, 76 cm Hg). The effective distance, $d$, is the distance in standard air for which $n_{eff} = n_{act}$. From the ideal gas law,

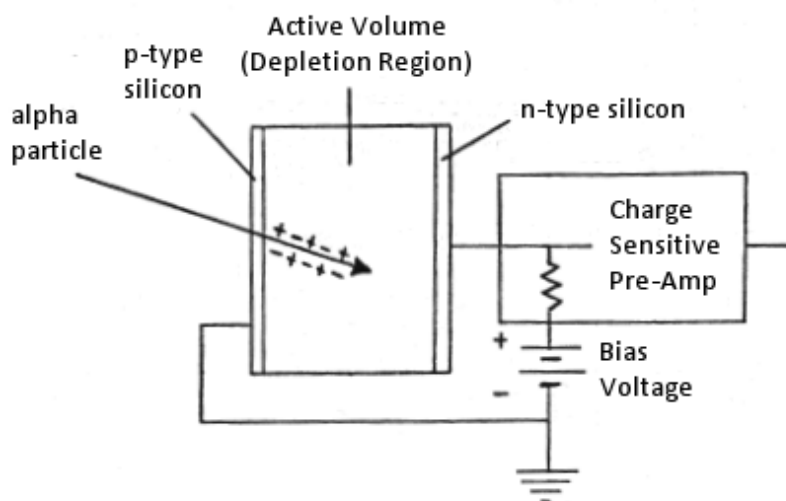$$\frac{pA\ell}{R(T+273°)} = \frac{(76 \text{ cm Hg})Ad}{R(15° + 273°)} \tag{1}$$

where $A$ is the cross-sectional area of the chamber and $R$ is the Universal Gas constant. Solving for $d$ yields:

$$d = \left( \frac{(288°)\, 7.8 \text{ cm}}{76 \text{ cm Hg}(T+273°)} \right) \cdot p \tag{2}$$

where $T$ is room temperature in °C and $p$ is the actual chamber pressure in cm Hg. Thus data measured as a function of air pressure can be easily converted to a function of source-detector separation in standard air. i.e. The effect of increasing the chamber air pressure is equivalent to having standard air and increasing the source-detector separation.

The detector used in this experiment consists of a silicon crystal which has been manufactured so that part of it is *p*-type and part is *n*-type. Thus the crystal contains a *p-n* junction. At a *p-n* junction, electrons from the *n* zone migrate to the *p* zone where they combine with holes to leave a thin layer on both sides of the junction that is depleted in charge carriers (the depletion region). The size of the depletion region is enlarged by applying an external voltage ($\approx 50$ V) to produce a reverse bias across the crystal so that its *p* end is negative and its *n* end is positive. The depletion region is the active part of the detector. When a charged particle such as an alpha particle passes into the depletion region, new electron-hole pairs are created by the ionization which occurs as the alpha particle loses energy to the crystal atoms. These new electrons and holes are attracted to the ends of the crystal where they produce a measurable voltage pulse in a charge-sensitive pre-amplifier. The size of this voltage pulse is directly proportional to the energy deposited by the particle; and if the particle stops in the crystal (as is the case in this experiment) the voltage pulse provides a measure of the particle's energy. To reduce energy loss outside the active zone, the *p*-type region and its electrical contact are made as thin as possible. Figure 5 is a schematic diagram of a semiconductor detector.
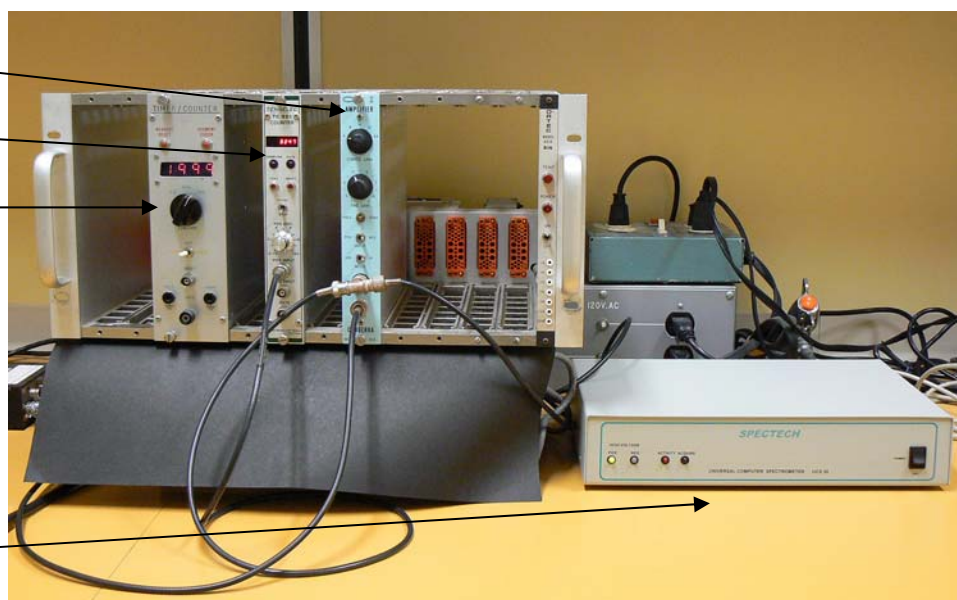
**Figure 5**

The output voltage pulse from the pre-amplifier is further amplified and shaped by the pulse amplifier.  The output of the pulse amplifier is split, with signals going to a counter and the multichannel/pulse height analyser (UCS 30 unit).



Amplifier

Counter

Timer

Multichannel
Analyser

**Figure 6 – Alpha Electronics**

The counter counts each alpha particle pulse.  Turning the counter and adjacent timer on and off simultaneously allows measurement of the alpha particle count rate.

The UCS 30 unit analyses the alpha particle voltage pulses according to magnitude.  Each pulse is assigned a channel number proportional to its voltage (i.e. the analogue voltages are digitized).  The number of alpha particle pulses corresponding to a specific channel number is recorded by the computer for each of the channels.  The monitor displays number of alpha particle pulses versus channel number.  Since the detector output is proportional to the energy of the impinging alpha particle, and the pre-amplifier, amplifier, and UCS 30 responses are linear,

the display is proportional to a plot of number of alpha particles versus energy. That is, the computer displays the energy distribution of the alpha particles after they have traversed the source-detector distance. Figure 7 shows a typical monitor display.
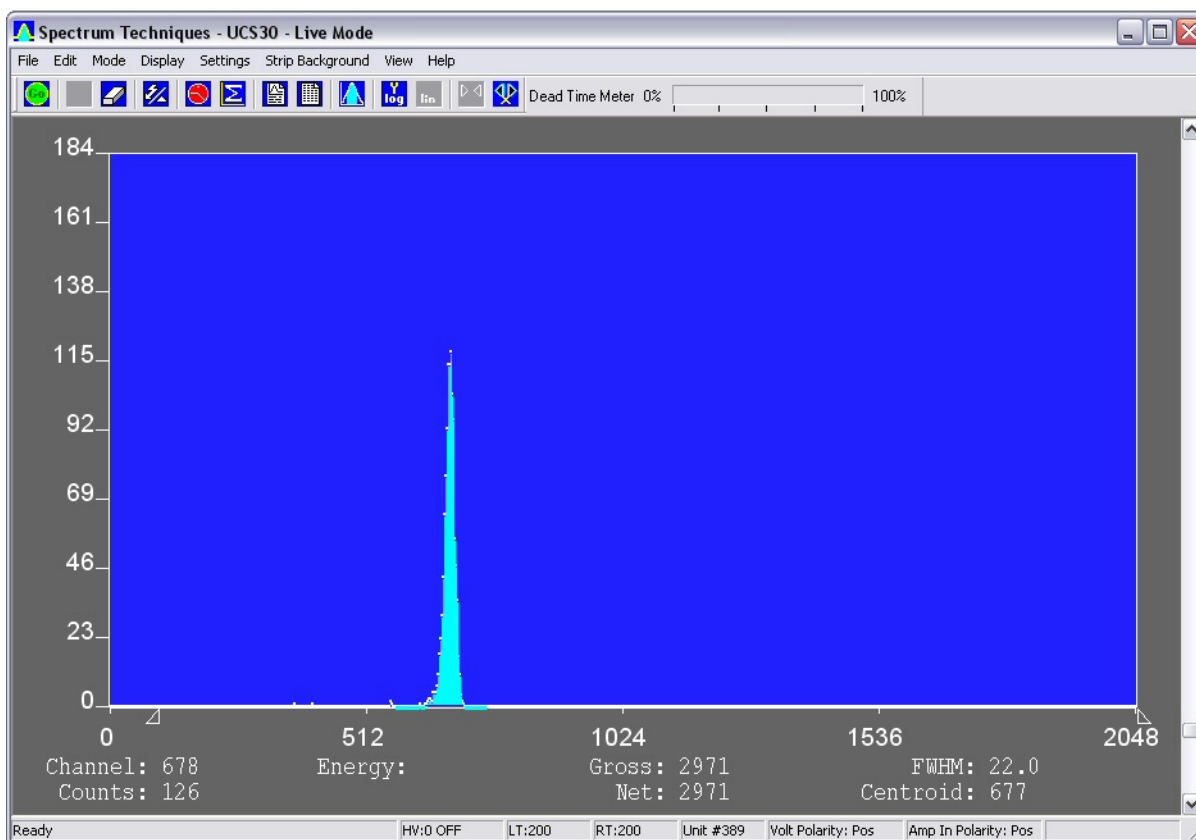


**Figure 7**

Note that although the alpha particle source is monoenergetic, there is a distribution of alpha particle energies around a peak value. This is due to the various types of straggling discussed previously. The computer program allows determination of the channel number corresponding to the peak energy.

**Procedure and Experiment**

Diffusion Cloud Chamber

The diffusion cloud chamber part of the experiment involves making a number of qualitative observations. The lab instructor will set up the cloud chamber sometime during the lab period. In the meantime, proceed with the Range of Alphas part of the experiment.

1. A number of radioactive sources are provided for use with the cloud chamber. Insert each of the sources and record your observations. Tracks due to alpha particles will be heavy, short, and straight; tracks due to beta particles will be light, long, and straight; and tracks due to gamma rays will be short and crooked. Which types of radiation did you observe?

2. With no source in or near the chamber, what do you observe? You should be able to see tracks due to cosmic radiation and radon gas.

For more information on the diffusion cloud chamber, read the pamphlet provided in the laboratory.  (Please leave this pamphlet in the lab when you are done the experiment.)

Range of Alphas Experiment

1.  Using the thermometer provided, measure and record the room temperature.

2.  Check that the needle valve is closed.  Open valve A and evacuate the system with the mechanical pump.  When the manometer (mercury gauge) reads essentially zero pressure (i.e. when the mercury levels in the two arms are at the same height) close valve A and turn off the pump.

3.  Turn on the electronics rack.

4.  The detector voltage is provided by two power supplies.  Turn on the top power supply and slowly increase the voltage from 15 to 30 V.  Then turn on the lower power supply and slowly increase its voltage from 15 to 30 V.  (At the end of the experiment, perform this step in reverse to reduce the voltage and shut off the power supplies.)

5.  Log-in to the computer (there is no password).

6.  Turn on the UCS30 device.

7.  Double-click on the UCS30 icon on the desktop.

8.  ***Click on the Mode menu and select 'PHA (Direct In)', the 3$^{rd}$ item on the list***.

9.  Data acquisition is controlled using the buttons on the toolbar.  For the most part, the functions of these buttons are obvious, and a ToolTip will appear if you hover over a button.

    Data acquisition is begun by clicking the 'GO' button.

    Data acquisition is stopped by clicking the 'STOP' button.

    Data is deleted using the eraser button (3$^{rd}$ from left).

    Data can be acquired for a pre-set time by clicking the clock button.  Ensure that 'Live Time' is selected.

    To determine the total number of counts in some region, or to determine the channel number/energy of a peak in the spectrum, a region of interest (ROI) must be defined.  This is done using the ROI button.  A ROI is defined by placing the cursor at the left edge of the desired region and then clicking with the left mouse button and dragging the cursor to the right edge of the region.  The ROI will change colour to show the region that has been selected.  The total number of counts in the region is given by the GROSS number (not the NET number).  The CENTROID is the channel number or energy of the peak within the ROI.  To clear the ROI, go to Settings $\rightarrow$ ROIs.

    The vertical axis can be toggled between a linear or logarithmic scale with the 'Y/lin' and 'Y/log' buttons.  The vertical axis scale is changed by moving the slider at the far right side of the program window.

9.  Measure the alpha particle count rate (using the counter and timer) and the channel number corresponding to the peak residual alpha particle energy (using the computer) for air pressure increments of 3 cm Hg, starting with $p = 0$.  (Note that the pressure in the chamber is given by the height difference of the mercury levels in the two arms of the manometer.)

10. Note that these measurements can be done at the same time.  (The counter and computer can accept data simultaneously.)  The count rate should remain relatively constant, and then drop

off rapidly once the air pressure is high enough so that most of the alphas are stopped before they reach the detector.  Use smaller pressure increments in this region.  The computer peak channel numbers should decrease steadily as the pressure is increased, because the increased number of collisions due to the increased number of air molecules means the alpha particles have less energy by the time they reach the detector.  It may not be possible to determine peak channel numbers near the air pressure at which the alpha particles have lost most of their energy.  (Adjust the X scale on the display to show 0 to 2048 channels.)
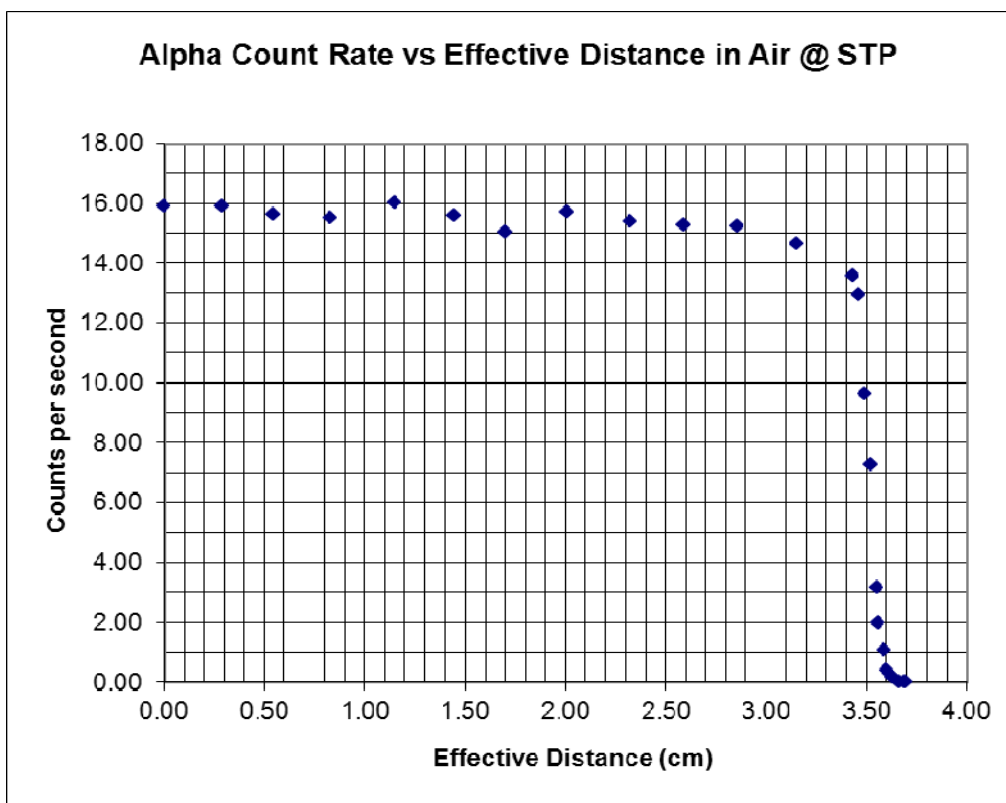
11. When you are sure you have collected all the required data (check with the lab instructor), turn off the equipment as follows:
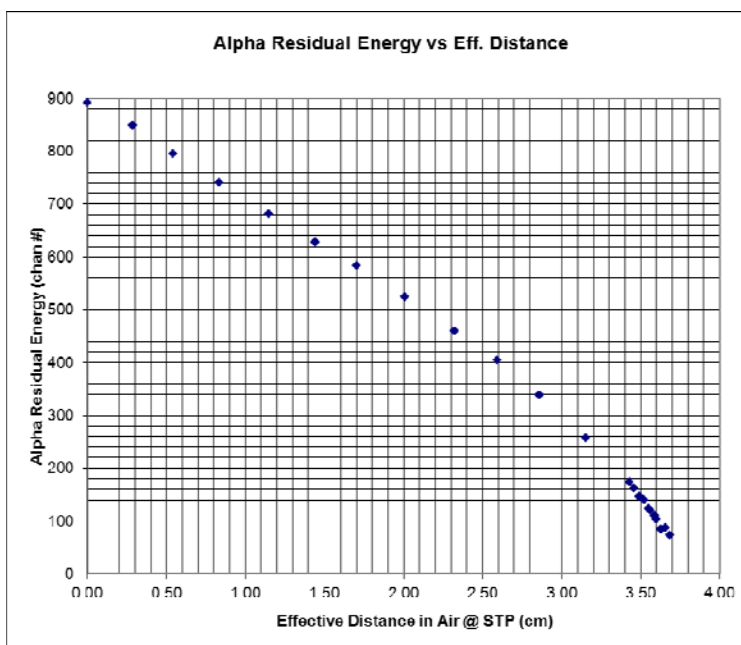
   - Close the UCS 30 program.
   - Turn off the UCS 30 device.
   - Logout from the computer.
   - Turn off the electronics rack.
   - Decrease the power supply voltages to 15 V and turn off.

## Analysis

Convert air pressures to effective source-detector distances in standard air.  Make plots of count rate versus effective distance, and peak channel number versus effective distance.  From each of these graphs determine a value for the range in standard air of $^{241}$Am alpha particles.  The count rate curve may have to be extrapolated to account for straggling (see Figure (2)), and the peak channel number curve will have to extrapolated to the *x*-axis because of the lack of data near the pressure corresponding to the range in standard air.

Typical plots are shown below:

Alpha Residual Energy vs Eff. Distance

Average the two range values obtained and determine the $^{241}$Am alpha particle energy from interpolation of Figure 3. Compare your energy with the accepted value of 5.486 MeV.

Using your experimental alpha particle energy and the peak channel number corresponding to $p = 0$, calculate the conversion factor, $N$, between channel number and energy.

Determine the alpha particle energy loss per unit distance ($-dE/dx$) at various effective source-detector distances. This is done as follows:

   a) Let $C_1$ be the peak channel number at an effective distance of $d_1$ and let $C_2$ be the peak channel number at an effective distance of $d_2$.

   b) The value of $-dE/dx$ at an effective distance of $\frac{1}{2}(d_1 + d_2)$ is given approximately by:

$$-\frac{dE}{dx} = \left(\frac{|C_2 - C_1|}{d_2 - d_1}\right) \cdot N$$

   That is, the slope of the line between two consecutive data points is approximately equal to the instantaneous rate of change of the actual curve at the midpoint between the two data points.

   c) A more accurate method of determining $-dE/dx$ values would be to determine the slopes of tangents to the peak channel number versus effective distance curve.

Plot energy loss per unit distance ($-dE/dx$) versus effective source-detector distance. Compare the shape of the graph with the curve shown in Figure (1) and discussed in the theory.

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