

Range of Alpha Particles in Gas

(note, this is abridged from full Nuclear Decay laboratory file)

1. References

1. A.C. Melissinos, *Experiments in Modern Physics*, pp. 155-165, pp. 208-217, (Academic Press, 1966, New York).
2. H.A. Bethe and J. Ashkin, *The Passage of Heavy Particles Through Matter* in E. Segre, *Experimental Nuclear Physics Vol. I*, pp. 166-251 (J. Wiley & Sons, 1953, New York).
3. G.F. Knoll, *Radiation Detection and Measurement*, sections A, D, F. (J. Wiley & Sons, 1979, New York).
4. Nicholas Tsoulfanidis, *Measurement and Detection of Radiation 2nd ed.*, pp. 96-97, 235-261, Taylor & Francis Publishers, Washington DC, 1995.
5. D.W. Preston & E.R. Dietz, *The Art of Experimental Physics*, (1991), pp. 331–344.

2. Purpose [NOTE, SEE ALSO Wisconsin manual on same sort of experiment]

The purpose of this experiment is

- a) To determine the range of 5.48 MeV alpha particles in air at various pressures.
- b) demonstrate the relationship

$$\frac{dE}{dx} \propto \frac{1}{E}$$

NOTES ADDED 1/09: Besides doing this experiment in AIR, we provide argon and helium for you to try to use and compare results. You should plan to dig up your own background on the difference in the range in different gasses. The instructions here are for “air” at different pressures. You can also change the distance, the gas, and so on. Be creative, be safe, ask questions.

3. Apparatus

The apparatus for this experiment consists of a vacuum chamber in which a solid-state detector and ²⁴¹Am source are permanently mounted - **DO NOT ATTEMPT TO OPEN THE CHAMBER AND REMOVE EITHER THE SOURCE OR THE DETECTOR**. The source is movable up and down by means of a rack-and-pinion drive. Associated electronics, described later, include a preamplifier, an amplifier, a personal computer-based multichannel analyzer (Pocket MCA-8000), a bias supply, a pulser, an attenuator, an oscilloscope, and a network printer. There is also a mechanical vacuum pump for evacuating the chamber and a digital manometer gauge.

4. Alpha particle detector and chamber

The solid state charged particle detectors are commonly made of a semiconductor such as silicon or germanium. There are three common technologies of making these state-of-the-art detectors: surface barrier on *n*- or *p*-type silicon; surface barrier on lithium compensated silicon [Si (Li)], and ion-implanted silicon. Basically all processes start with a high purity silicon wafer (usually *n*-type). In surface barrier types, the wafer has a thin layer of opposite type material (such as *p*-type) to make it a diode. Then the wafer is epoxied at the end, chemically treated and metallized to make the contacts. Contact to the front (*p*-type) surface is made by a thin gold film of only about 40 $\mu\text{g}/\text{cm}^2$ thickness, and to the back *n*-type wafer by a thin non-rectifying aluminum contact of similar thickness. In ion-implanted variety, the diode wafer is doped by ions, typically boron, to make the windows and contacts. Ion-implanted types have lower leakage current, better resolution and are more rugged than surface barrier types.

The solid-state detector used in this experiment is of the ion-implanted variety. The current detector is *Ortec Model TU-014-050-100, Serial No. 36-104FF18*. The detector specifications are mounted below the vacuum chamber. This very modern detector is, as described above, a diode made of silicon with a thin *p*-type layer on the surface of a high-purity *n*-type wafer. In operation, the detector is reverse-biased by a *POSITIVE* bias supply so that the *p*-layer is 50 V negative with respect to the *n*-layer.

When a charged particle travels through the silicon, it loses energy and creates free electron-hole pair at a rate of one electron-hole pair for an energy loss of 3.62 eV at a temperature of 300K. The production of electron-hole pairs is nearly independent of particle energy and particle type. Thus the total amount of ionization is proportional to the energy of the incident particle, as long as the particle stops within the sensitive depth of the detector (as in this experiment) and the bias voltage across the sensitive region is large enough to separate the charge carriers before they recombine. The detector diode has a sensitive area of 50 mm^2 , and, with proper bias and associated electronics, provides an alpha particle energy resolution of 14 KeV, limited by the shot noise generated by the reverse-biased junction. Since both the electrons and holes have large mobilities (electrons, 1350 $\text{cm}^2/\text{V.s.}$; holes, 480 $\text{cm}^2/\text{V.s.}$), and the collision distances are short, the detector provides a very fast response time - the order of a few nanoseconds. The detector is mounted at the top of the vacuum chamber, the dimensions of which are shown in Figure 6. Note that the detector and the source are collimated so that the path from the source to the detector is well defined.

5. Electronics and Calibration Procedure

The basic arrangement of the electronic components is shown in Figure 7.

The detector output is a current, but it is the total charge which is proportional to the energy of the incident particle. Thus the preamplifier must integrate the current and produce a voltage which is proportional to the total charge flowing into the preamplifier input. This integration is accomplished by a very sensitive FET-input operational amplifier. The detector is biased through the preamplifier circuit. To avoid damage to the FET, the bias must be raised VERY SLOWLY from zero. Similarly, before turning the apparatus off, the bias should be

slowly returned to zero. Otherwise, the transient resulting from sudden application of the full bias voltage (50V) may destroy the FET and ruin the preamplifier. The reverse current at 50 Volt bias for this detector was 28.4 nA in May 1997. The Canberra preamplifier has 110 M Ω in series with the detector. The voltage across the detector is smaller than the applied bias voltage by the drop across the resistance.

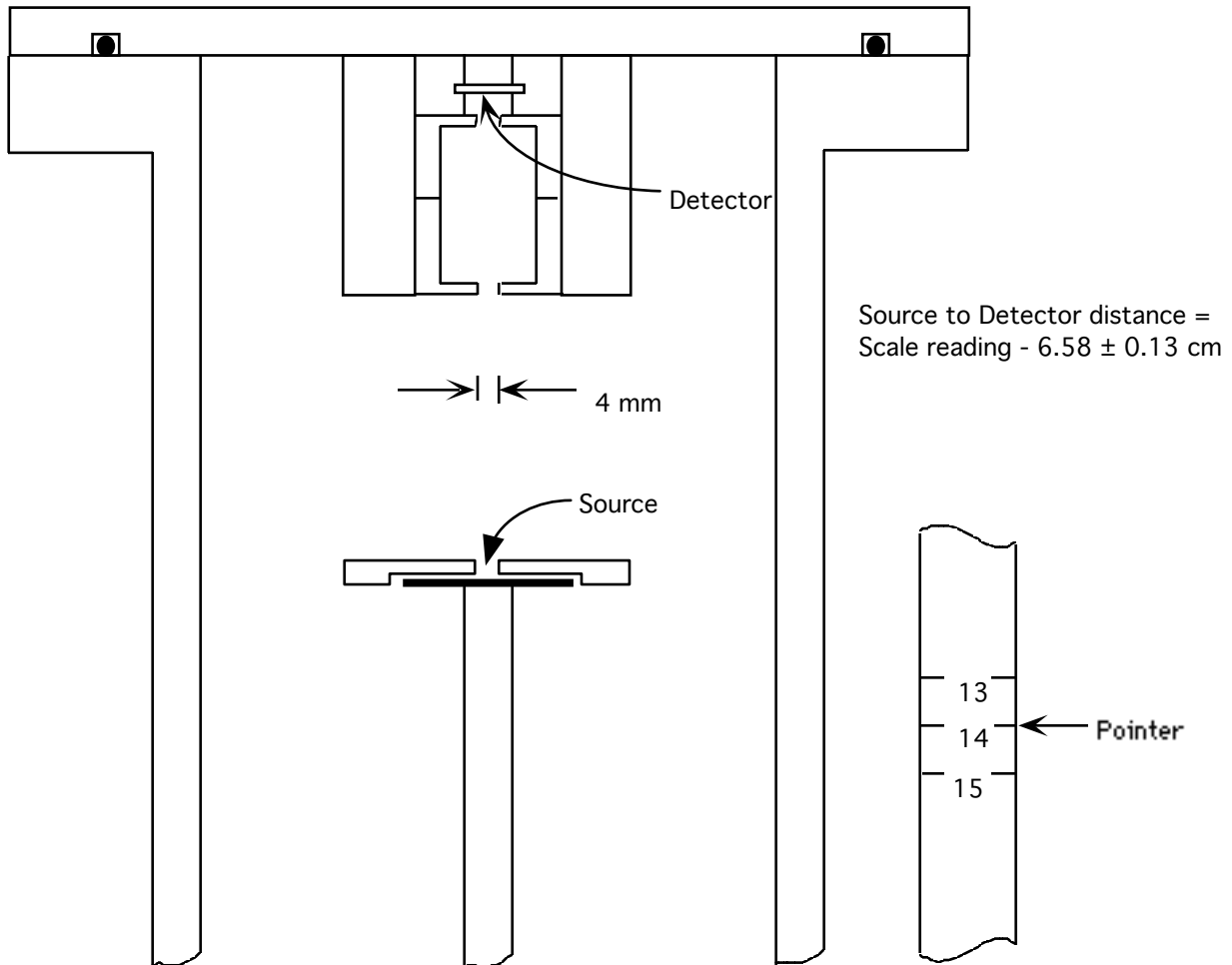


Figure 6. Source and detector dimensions

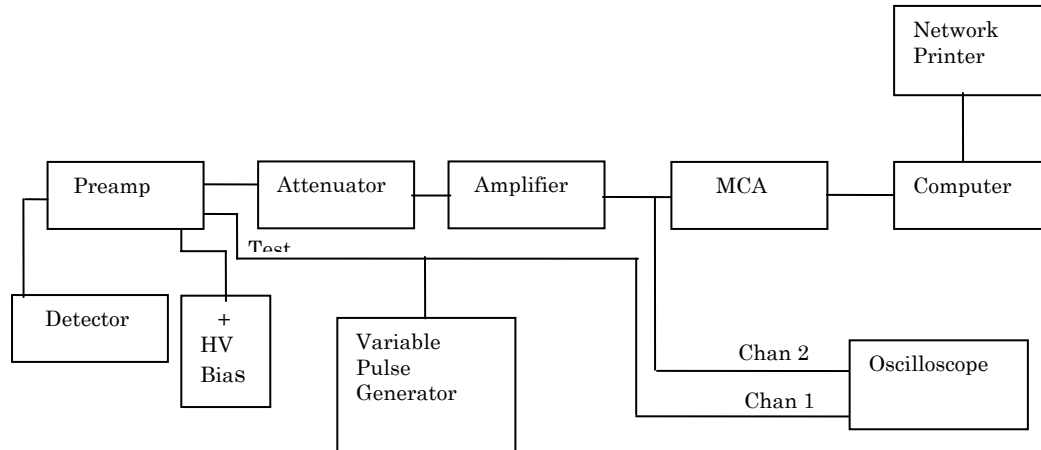


Figure 7. Block diagram of electronics

The fixed gain of the preamplifier is sufficiently high that with maximum input signal the following amplifier (*Ortec model 450*) can be overloaded, even at minimum gain setting. For this reason, a variable attenuator may be inserted between the preamplifier output and the amplifier input. The amplifier output is fed into a PC-based “Pocket” multichannel analyzer (MCA-8000A). See Appendix A. The MCA accepts 0 – 5 or 0 - 10Volt positive input signal, switchable on the front panel. See Figure 8. This arrangement permits precise measurement of the spectrum of the pulse heights.

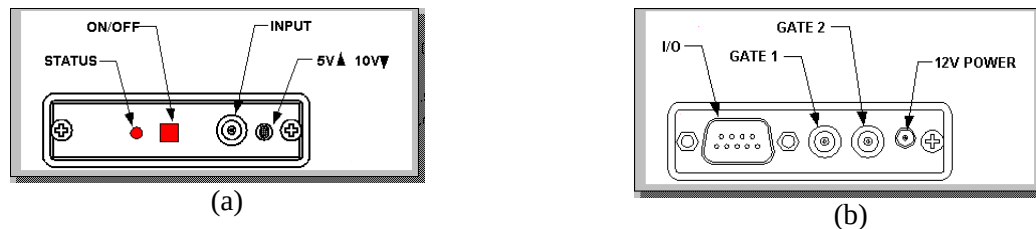


Figure 8. (a) Front panel, (b) rear panel – of the MCA-8000A.

Since it is the total charge produced by the detector, rather than a voltage or current, which is proportional to the incident particle energy, a special calibration technique must be used. You will employ a variable amplitude pulse generator, contained in the same module as the pre-bias voltage supply, and a capacitive divider, which is inside the amplifier. The basic circuit is shown in Figure 9.

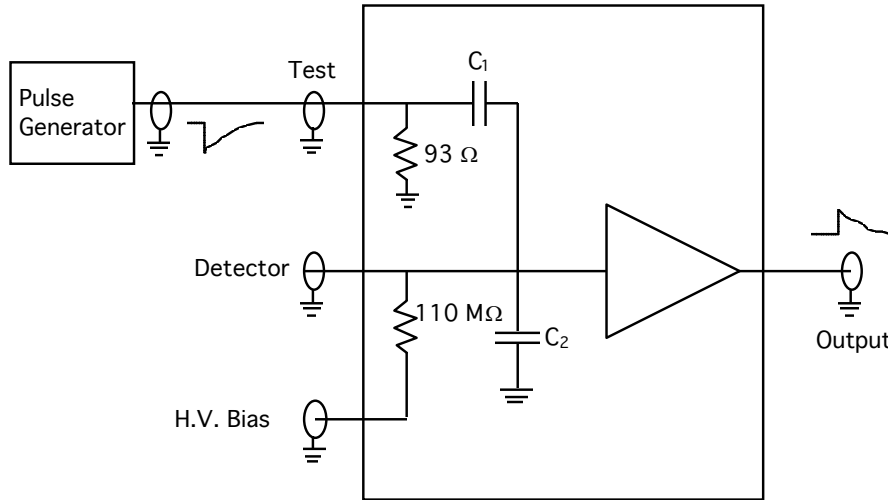


Figure 9. Detail of calibration procedure.

C_1 is a small, very accurately known capacitor. C_2 represents the distributed capacitance to ground of the FET input and BIAS connections and is about 50 pF. When a sudden voltage pulse is applied to the *TEST* input, an equal amount of charge is deposited on C_1 and C_2 . Since C_1 is so much smaller than C_2 , almost all the voltage is developed across C_1 . (Remember $V = Q/C$). C_1 then discharges into the charge sensitive FET pre-amp. Since the pulse height V is measured at the pulse generator output and C_1 is accurately known, the charge in the test pulse can be computed. Knowing that one electron-hole pair is liberated for each 3.62 eV of energy deposition this test charge can be converted to a practical energy.

$$E(\text{MeV}) = Q_{\text{test}} \times 6.24 \times 10^{18} \left[\frac{\text{eh pairs}}{\text{coul.}} \right] \times 3.62 \left[\frac{\text{eV}}{\text{eh pair}} \right] \times 10^{-6} \left[\frac{\text{MeV}}{\text{eV}} \right]$$

$$\text{i.e.} \quad E(\text{MeV}) = 2.26 \times 10^{13} Q_{\text{test}}$$

In other words, a particle of energy E stopping in the detector would produce a pulse with the same charge Q_{test} where $Q_{\text{test}} = C_1 V_{\text{Pulser}}$. The output of the charge sensitive pre-amp is a voltage pulse whose amplitude is proportional to the particle energy. This signal runs through the attenuator and amplifier and ultimately produces a peak on the MCA which corresponds to a known energy. Thus, the pulser can be used to produce standard test energies to calibrate the MCA scale.

The source of alpha particles in this experiment is a thin layer of Americium-241. Its characteristics are described in Appendix B.

6.

Vacuum System

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A schematic of the vacuum system is shown in Figure 10. The experiment should always start out with the chamber at atmospheric pressure. The digital manometer gauge reads absolute pressure in mmHg.

i. To lower the pressure:

1. Make sure that *B* and *C* are completely closed.
2. Start the pump if it is not already on.
3. Open *A* if it is not already open.
4. Close *A* when the desired vacuum is reached. At any time the chamber should not be pumped down below 50 mmHg since at lower pressure, breakdown will occur and the particle detector will be damaged.

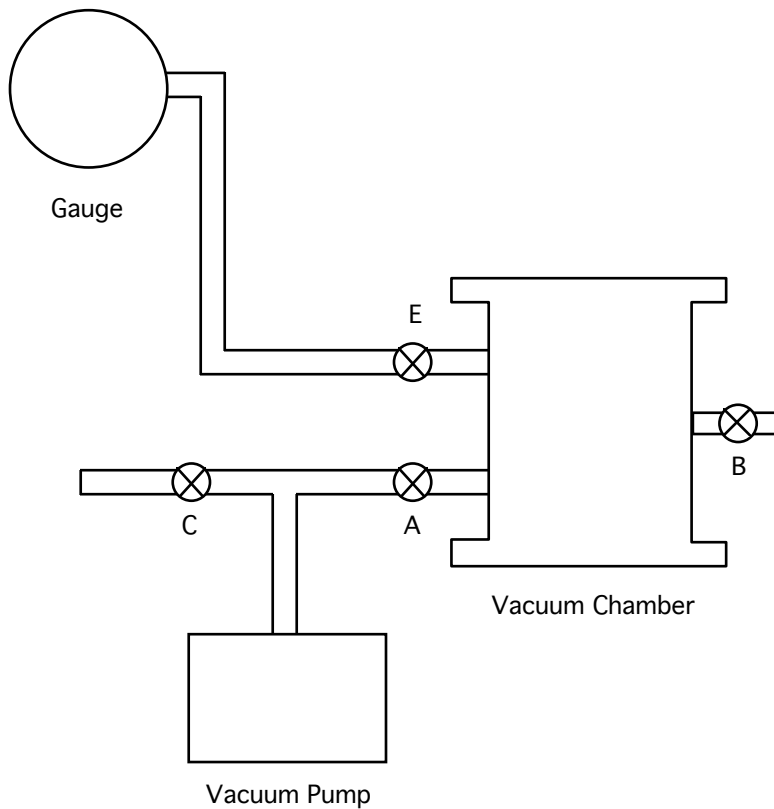


Figure 10. Vacuum System

ii. To increase the pressure:

1. Make sure *A* is closed.

2. Open *B* to admit air until the desired pressure is reached.

WARNING: *The solid-state detector will stop working after a large (but fixed) number of counts. The threshold dose for radiation damage in silicon begins at 10^9 alpha particles/cm². When not actually taking data, let air into the vacuum chamber. Do not leave the source close to the detector for long periods of time. In short, try to do your lab with as little wear on the detector as possible. We would like this one to last for several years.*

7. **Initial Procedure**

1. Connect the circuit as shown in Figure 8 (or, if already connected, check to be certain that it is correct). **DO NOT TURN ON THE POWER TO THE NIM BIN YET.**
2. Be certain that the bias supply switch (on back of unit) is set at the *POSITIVE* position and that the control dial on the front is fully *COUNTER-CLOCKWISE* so that it reads zero.
3. Turn on the power. *SLOWLY* (taking about 30 seconds) and smoothly increase the bias voltage to about 40 V, as indicated on the meter. Due to the offset of the meter scale, the actual voltage output is about 45 volts. Set the *Ortec Model 450 Amplifier* for: positive input polarity; minimum gain; integrate and differentiate *OUT*; unipolar output to positive 10V; *BLR* (Base Line Restorer) to high. The Kay Attenuator should be set to out, i.e., at 0 attenuation.
4. Move the source as close as possible to the detector. Note the source to detector distance. Now observe the pulses on the oscilloscope. Typically, they should be about 3 V high. Note the shape of the tops of the pulses.
5. Move the source away from the detector until the pulses disappear into the noise. Note the source to detector distance.
6. Turn on the mechanical vacuum pump (if you have not turned it on) and slowly decrease the pressure to about 50 mmHg as indicated on the digital pressure gauge. Do not reduce the pressure below this point. The pulses should reappear on the scope.
7. With the amplifier still set on minimum gain, adjust the attenuator until the source pulse peaks are about 4 V, as observed on the oscilloscope. Compare the shape of the pulse tops to those observed in step 4. Why is the attenuator needed? Return the system to atmospheric pressure by using valve *B*.
8. Use a BNC *T*-connector to run the amplifier output to the scope via BNC cable and to input of the MCA using a BNC-to-Lemo connector. The Lemo input of the MCA is located at the front right of the MCA. Make sure that the input level switch on the MCA is down for a 10 volt maximum input level. The input of MCA has overload protection of ± 15 volt only. The MCA software has *Help* menu which has documentation for operation and example spectra.
9. With the MCA collecting data, vary the amplifier gain, air pressure, and source distance. Observe how the peak moves, and how its counting rate varies. The channel numbers of the cursors are displayed on the screen. These can be used to determine the peak channel. Adjust the gain of the amplifier (as well as the attenuator if necessary) so that the signals from the detector do not saturate any component in the circuit, and so that the largest amplitude signals

appear near the right edge of the display. The MCA will be saturated if the input is over the set voltage (5 or 10 Volt).

10. Connect the pulser to the scope and to the pre-amp test input. The pulser has a fairly high output impedance, therefore, it is important to measure the pulse height under loaded conditions since the pulser is loaded when connected to the test input. The load resistor at the test input is 93 Ohms. To provide the same conditions you should use a 93 Ohms coaxial cable for the connection, and terminate the cable with a 93 Ohms resistor at the oscilloscope. Using the test pulse voltage, the equation given earlier, and the capacitance marked on the pre-amp case, calculate the equivalent energy for the test pulse in MeV. Find the channel numbers which correspond to several different energies, making full scale on the screen about 6 MeV. The relationship between channel numbers and energy should be linear. A slight offset for zero energy is normal. Observe the amplifier output pulses on the scope to make sure they are not distorted at 6 MeV. The system is now calibrated.

8. Measurements and Report

After the calibration is completed and you are certain that you understand all the controls on the apparatus, remove the test pulse input and proceed to take data.

Starting again at atmospheric pressure in the chamber, move the source away from the detector until the counts and observed pulses stop completely and lock the source in position. Using the dimensions shown in Fig. 7, calculate and record the actual separation between the source and detector. *UNDER NO CIRCUMSTANCES SHOULD YOU OPEN THE VACUUM CHAMBER.*

Vary the vacuum pressure in small steps (8 values or more) between one atmosphere (~760 mmHg) and 50 mmHg. Do not let the pressure decrease below 50 mmHg. At each pressure note the peak channel on the PCA. All your points can be accumulated on one spectrum which can be printed out by the printer. Make sure each pressure peak is collected for the same period of time.

Results required:

- 1) Your energy calibration and its result with errors. Did it work within the accuracy of the system?
- 2) At least one set of pulse height spectra for 8 or more pressures, separate or combined.
- 3) Plot the counting rate versus air pressure, and explain the behavior of the curve. (Note that the counting rate is **not** given by the peak height!) Why do the peaks get wider with increasing pressure?
- 4) Plot E^2 vs. p with error bars drawn in, where E and p are energy and pressure, respectively.
- 5) Plot E^2 vs. X_{eff} . $X_{eff} = Dp/P_{atmospheric}$ where D is the source to detector distance measured earlier (in cm) and p is the same as in 4. Use the slope of this graph to determine k in the expression $0.5E^2 = kX_{eff}$. Differentiating gives $dE/dx = k/E$ showing that the energy loss per unit distance varies as $1/E$. The E^2 vs. p plot was not exactly linear however, so k itself may

have some energy dependence. Discuss this issue in terms of your experimental errors. This $1/E$ dependence is characteristic of heavy charged particles in a certain energy region. See p. 160 of Melissinos. The log-log dE/dx vs. E curves show that k is constant for certain energies. What is this energy range for alpha particles in air?

- 6) You have made two different types of measurements in this experiment. First you found the range in air at STP for one energy, 5.4 MeV. Then you measured energy loss per unit distance for various particle energies in the second part of the experiment. These two measurements are related. The range of the particle is that distance over which all its kinetic energy is dissipated. We can therefore integrate as follows:

$$\frac{dE}{dx} = \frac{k}{E},$$

$$\int_0^{R_0} dx = \frac{1}{k} \int_0^{E_0} E dE$$

where R_0 = the particle range, and E_0 = the initial energy, then

$$R_0 = \frac{E_0^2}{2k}$$

$$\ln R_0 = 2 \ln E_0 - \ln 2k$$

Thus, when k is constant, E_0 and R_0 will be linearly related on a log-log plot. See p.162 of Melissinos. Use this graph to check your range measurement. You will need to convert your reading in cm into density-reduced units (gm/cm^2). Do this using the density of air at STP ($1.225 \times 10^{-3} \text{ gm}/\text{cm}^3$) and the ratio of the temperatures, for example (273K/295K). How does your range compare with that predicted by the graph? Do you expect them to be the same?

9. Shutdown Procedure

1. When you have finished your measurements, slowly reduce the bias voltage to zero before turning off the electronics.
2. Turn off the electronics and the vacuum pump.
3. Readmit air into the chamber and the system.
4. Move the source as far away from the detector as possible.

APPENDIX A

The following discussion is about the use of the Amptek Multichannel Analyzer (MCA) which is used in this experiment. Refer to the *Help* menu of the Pocket MCA-8000A software to learn the details of the MCA. If you wish, you may download the free software from the Amptek website (<http://www.amptek.com>) and analyze your spectra on your home computer. There are examples of various spectra to view and practice in the free software.

The output of the MCA is connected to the COM1 port of the computer. The MCA is also in series with an attenuator to prevent saturation of the MCA. Since the attenuator controls the signal level, channel width (on the horizontal axis) can be varied. Once the energy calibration has been set, do not change the attenuator toggle switches.

Turn on the software by double-clicking the *MCA* icon on the desktop. “Starting PMCA” dialog box will appear. To open a file, select “Open a File”. To acquire data, select “Connect”. There are 6 MCA menu commands (*File, Edit, MCA, Display, Analyze* and *Help*). Click *MCA >> MCA Setup* (or press F9 key) to observe the MCA’s status and note other parameters. Leave the *MCA security code* to the default number of ‘0’ and the baud rate to ‘115200’ bits per second. As an exercise, browse through *Help* menu (or press F1 key) to learn about the details of the software. At *MCA >> Acquisition Setup...*, you may need to tweak the *Threshold* number to a smaller number (typically 10) in case if you are not getting any spectra at all. *ADC Gain* is typically set at 1024. Once you are comfortable acquiring the spectra, experiment with different *preset time, scale (linear or log)* and other parameters to get the best spectra on the screen.

To start (and stop) data acquisition, select *MCA >> Start acquisition* or *Stop acquisition* (or press Space Bar or F3 key). MCA begins its acquisition and its red LED flashes on the front panel. Spectrum is updated with new data approximately every second.

The screen display shows 3 areas: the Plot Pane, Info Pane and Select Pane. Plot Pane displays the spectrum. Directly clicking at a point in Plot Pane shows the cursor. The Info Pane displays the current status of the MCA and the peak information, at the right side, if a Region of Interest (ROI) has been set. To set ROI, click *Edit ROI* button on the toolbar. You will notice the mouse cursor will change to an up-down arrow. Left click the mouse and drag it over the desired region. This will set the ROI. Additional ROIs can be set by same procedure. To exit the ROI mode, click the *Edit ROI* toolbar again. The cursor would change back to normal cursor. One use of ROI is to seek peak information. If you click in an ROI area, peak information will be displayed in Info Pane.

The Select Pane displays cursor information (channel location, channel counts), x and y-axis range settings, and the scale of the spectrum (linear, square root, and log) at the bottom of the Plot Pane. The four arrows at the right end of the Select Pane changes the ranges of the axes and show the data at the cursor. You may use the arrows of the keyboard as an alternative. The up down arrows changes the y-axis. The left and right arrow changes the x-axis cursor location and shows the counts. Left and right arrow with Control key would select the next ROI.

You may save your spectrum by selecting *File >> Save as* command. The file can be re-opened using MCA software.

APPENDIX B

The source of α particles in this experiment is a thin layer of ^{241}Am . Its characteristics are listed below.

^{241}Am ALPHA REFERENCE SOURCE (Half-life: 432.2 years)

α -energies : 5.4431, 5.4857 MeV; γ -energies : 0.03 - 0.06 MeV

Total disintegration energy, $Q_\alpha = 5.63781$ MeV

This type of source consists of a thin layer of ^{241}Am deposited by vacuum sublimation onto a lightly oxidized stainless steel disc of overall diameter 25 mm and thickness 0.5 mm. The diameter of the active area is approximately 7 mm.

Testing : Wipe test limits:

< 3 % removable activity from $3 \times 10^3 - 3 \times 10^4$ d.p.m. sources.

< 1 % removable activity from $3 \times 10^5 - 3 \times 10^6$ d.p.m. sources.

A test report is supplied for each source or batch of sources.

All sources are checked with a solid state spectrometer and, for alpha particles emerging normal to the surface of the

source, the energy distribution of the principal alpha emission is guaranteed to have a full width at half height of less than 20 keV. Calibrated sources are also measured under the same conditions as the type AMR-C sources above, and the rate at which alpha particles emerge from the source is certified to an accuracy of ± 2 % maximum error.

Nominal Activity	Uncalibrated Order No.	Calibrated Order No.
3×10^4 d.p.m.	AMR-12	AMR-22
$> 3 \times 10^4$ d.p.m.	AMR-13	AMR-23
3×10^6 d.p.m.	AMR-14	

