Alpha particle spectroscopy

Principle

The purpose of this experiment is to use an α-spectrometer, consisting of a silicon surface barrier layer detector, a preamplifier and a pulse height analyzer to study some of the properties of alpha particles.
When an alpha particle strikes the silicon detector a charge pulse is produced which is proportional to the energy of the incident alpha particle. This pulse is converted to a voltage and amplified by a preamplifier before being fed into a pulse height analyzer (PHA). The PHA allows the number of pulses whose peak lie within a certain voltage range to be measured. The range of voltages measured is determined by the "window" setting and can be expressed as either a fixed voltage (e.g. 100mV, 200mV or 500mV) or as a percentage of the base voltage. In manual mode the minimum voltage of the window is set by the base dial. In automatic mode the PHA sweeps the voltage window upwards from 0V to the value set on the "base" dial. The amount of time the PHA collects data for is determined by the "dwell time". In this experiment you will use the PHA in automatic mode and collect the data using the computer.

There are three parts to this experiment:

1. To calibrate the α spectrometer using the open ^{241}Am emitter
2. To measure the α-spectrum of the ^{226}Ra source and compare these to the decay products of ^{226}Ra
3. To measure the energy loss of α particles in air

NOTE: Radioactive sources are dangerous and should be treated with respect. When changing sources always keep the source cover on until the last moment before the source is reintroduced into the chamber. If you are in any doubt as to what to do at any stage ask one of the demonstrators for help. When not in use the sources are kept locked in the technicians office. Ask Pete or Saqib if you need one of the sources and make sure you give them back to them when you have finished for the day.

Theory

α particles penetrating the barrier layer of a semiconductor detector give rise to free charged particles along their path, the amount of charge produced is proportional to the energy of the incident α particles. These charge pulses are converted in the preamplifier of the α detector into voltage pulses, the peak values of which are again proportional to the charge in the input pulse. As a result of the linear operation of the main amplifier, a simple linear relation is obtained in the pulse height analyzer between the α particle energy and the height of the pulses analyzed by the discriminator.
An α emitter of known particle energy E_0, yielding pulses of height V_0, is used for calibration of the experimental layout. The α energy E of particles yielding pulses of height V is governed by the expression:

$$E = \frac{V}{V_0} E_0 \qquad (1)$$

For this experiment there are two types of source, open and closed. The closed sources have a thin metal cover over them, this results in a small shift in the energies of the α particles emitted from these sources as well as a broadening of the energy distribution of the α particles. The open ^{241}Am source does not have this cover and hence the α particles emitted from it have a well defined energy and can be used to calibrate the output from the PHA.

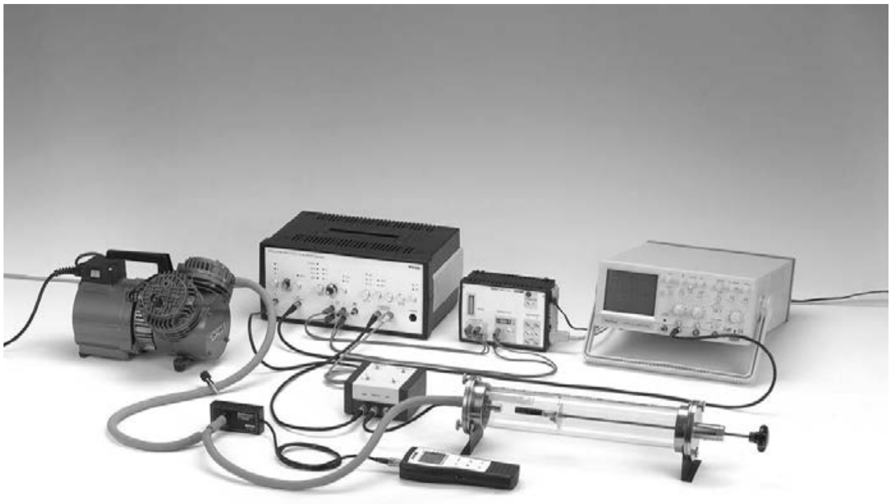

Fig. 1: Experimental set-up for α particle spectroscopy.

For the ^{241}Am source used here E_0 = 5.486 MeV.
Each ^{226}Ra source contains the following nuclides in the radium decay series (disregarding nuclides such as ^{218}At, ^{218}Rn, ^{210}Tl and ^{206}Tl which only occur with very low activities):

Nuclide	*Type of decay*	*α energy (MeV)*
^{226}Ra	α	4.78
^{222}Rn	α	5.48
^{218}Po	α	6.00
^{214}Pb	β^-	–
^{214}Bi	β^-	–
^{214}Po	α	7.68
^{210}Pb	β^-	–
^{210}Bi	β^-	–
^{210}Po	α	5.30
^{206}Pb	Stable	–

Table 1. The nuclides in the radium decay series with the α energies of the emitted particles

The energy spectrum of a radium source, which is in equilibrium with its decay products, is recorded and evaluated. The α energies found in this way are allocated to the corresponding nuclides of the radium decay series.

Part 1. Calibration of the alpha spectrometer

Note: a calibration is only valid if it is recorded under the same conditions as the measurement you want to calibrate. This means make sure to keep the source to detector distance to the values given in this script and **do not adjust the amplification on the PHA between measurements**.

Set-up and procedure

Fig. 1 shows the complete experimental layout. The α detector is enclosed in the vessel and the open americium source is screwed into the source holder inside the vessel. The remaining details of the layout can be seen in Fig. 1.

Preparation

- Open the vacuum chamber and screw the open ^{241}Am source onto the source holder.
- Switch on the vacuum pump and open the stopcock. Evacuate the vessel to ~5 hPa. Close the stopcock. (the vacuum is adequate provided that the pressure remains below 10 hPa).
- Bring the source to within about 1 mm of the detector. **Make sure you do not hit the detector with the source**
- Note the pulse height shown on the oscilloscope (time factor: ~10 ms/cm) and adjust the amplification on the pulse height analyzer so as to obtain a maximum pulse height of about 7 V.

Warning: The “Zoom” key on the PHA must not be pressed.

Setting of the Cobra3 basic unit

The cobra computer interface allows the PC to be used as a chart recorder. There are two outputs from the PHA which are connected to the two analogue inputs on the cobra unit. The x-output is being fed the “base” voltage whilst the y-output has a signal proportional to the number of counts within the measurement window.
Start the MEASURE software on the PC and start a new measurement. Use the following parameters in the measure software:

Get value:	every 200 ms
Start of measurement:	on key press
End of measurement:	on key press
Display:	Select analogue display 1 and 2 and Diagram 1 and 2
Channels:	Select analogue in 1 and analogue in 2
X data:	Analogue in 1

Range: Analogue in 1: ±10V, Analogue in 2: ±1V

Recording of the ^{241}Am spectrum

- The following pulse height analyzer settings are recommended: Window 1 %, Base 8 V, Dwell time 3.2 s.
- Make sure the PHA is set to AUTO.
- Press the “Reset” key.
- Press the “Start/Stop” key and record the spectrum.
- It is sufficient to scan a very narrow range on either side of the ^{241}Am-line (using the fast forward mechanism).

The recorded data can be exported from the measure software as a text file. The last two columns of this data are the x and y outputs from the PHA, recorded by the PC approximately every 200ms. This data can be imported into Sigmaplot or Origin (On the student network) to obtain a graph of intensity verses base voltage. As the peak of the open ^{241}Am source is know to occur at 5.486 MeV, the voltage scale can be calibrated in MeV using equation 1.

Part 2. Recording of the ^{226}Ra spectrum

The α spectrum of the ^{226}Ra source is then recorded without altering the amplification on the pulse height analyzer using the following procedure:

- Vent the vacuum chamber to air using the air admittance valve in the vessel (at the source holder side).
- Withdraw the americium source and in its place screw the radium source to the source holder.
- Close the vessel, evacuate once again to ~5 hPa
- Bring the source to within about 1 mm of the detector.
- The following pulse height analyzer settings are recommended: Window 1 %, Base 10V, Timing cycle 1.6 s.

Record the spectrum as for ^{226}Ra. Fig. 3 shows a typical ^{226}Ra pulse height spectrum with five lines allocated to the nuclides of the Radium decay series.

For the analysis of ^{226}Ra spectrum convert the measured pulse height into the corresponding energy values of the Alpha particles. For this purpose use the conversion factor obtained for the ^{241}Am calibration spectrum.

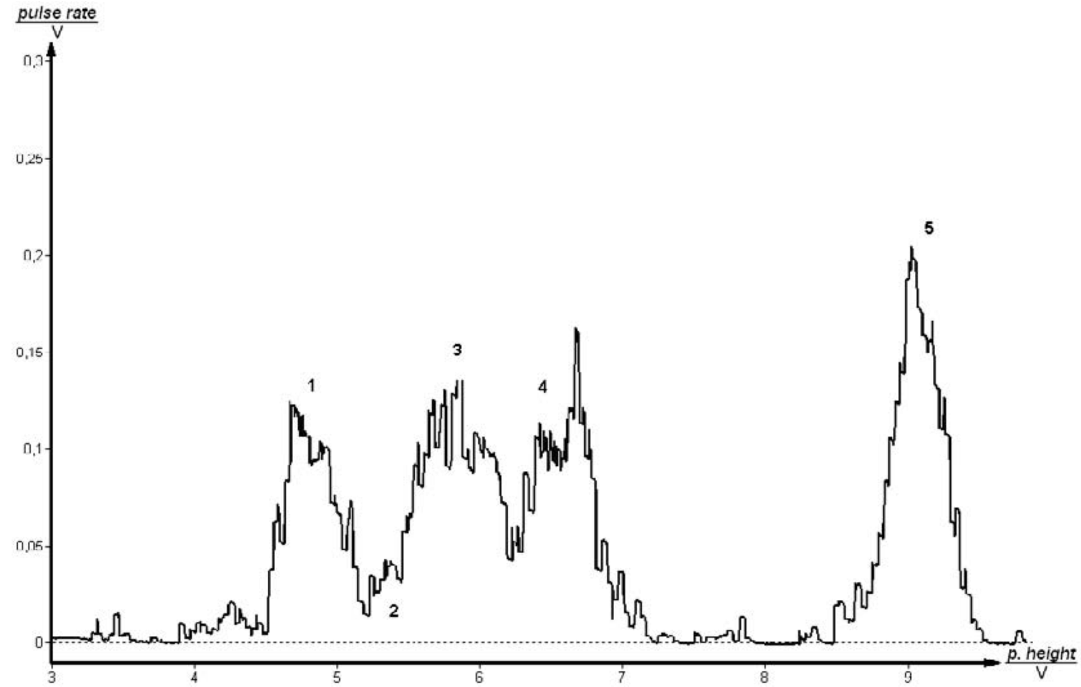

Figure 3: A typical spectra for the ^{226}Ra source.

After calibrating the spectra, compare the positions of the peaks with those given in table 1 and determine the average energy lost by an α particle as it passes through the cover on the source.

Part 3. Energy loss of α particles in air

The α spectra of the closed ^{241}Am source is to be measured as a function of the pressure in the chamber.

Principle

A study is made of the connection between the energy *E* of α particles and the path *x* travelled by them in air at standard pressure. The measurements recorded enable the differential energy loss *dE/dx* to be calculated as a function of *x*. To improve the measurement accuracy and to exclude the influence of different measurement geometries, the measurements are carried out in a vessel with a fixed distance *s* between the source and the detector, the pressure *p* being varied instead of the intervening distance. The path *x*, at which the same energy loss would occur under standard pressure (1013 hPa)*, is calculated from the formula:

$$x = s \frac{p}{1013\ hPa} \qquad (2)$$

* 1 hPa ≈ 1 mbar

Tasks

1. The spectrum of a covered ^{241}Am source is measured at a fixed distance s as a function of the pressure *p*. The distance *s* is selected in such a way as to correspond to the maximum range at the highest pressure measurable with the manometer used. The energy corresponding to the central points of the individual spectra are determined (after calibration of the measurement layout with an open ^{241}Am emitter, see 2.) and plotted as a function of the effective distance *x*. Using this data, the differential energy loss *(-dE/dx*) is then calculated as a function of *x* and again plotted on a graph.

2. The mean energy with which the α particles leave the covered americium source is determined by calibration against the open americium emitter (E = 5.485 MeV). (This value is required for the calculations in 1.)

Set-up and procedure

The distance between the detector located in the vessel and the ^{241}Am source (370 kBq), screwed to the adjustable source holder in the vessel, is 10 cm. The pressure is measured with a hand held manometer.

Preparation

- Evacuate the vessel until the vacuum gauge indicates approximately 0 hPa.
- Close the valve to the vacuum pump.
- Note the pulse height on the oscilloscope (with a time factor of about 200 µs/cm). Select the amplification value on the pulse height analyzer in such a way to obtain a mean pulse height of about 5 V. Warning: the “Zoom” key should not be pressed.
- Select the 500 mV window and a timing cycle of 1.6 s.

Recording of the spectra

A number of spectra are recorded in succession at different pressure values *p*, starting with *p* = 0 hPa and increasing the pressure by steps of ~25 hPa by means of a brief opening of the ventilation screw in the vessel.
At a pressure between 200 and 250 hPa the residual energy of the α particles will be so small that resolution of the spectrum from the noise is no longer possible. This brings the series of measurements to an end.

The final step is to determine the absolute value of the mean energy at which the α particles leave the emitter used in the preceding measurements. Replace the covered ^{241}Am source with the open source and record the spectra, at a pressure of ~0 hPa, make the distance between the source and detector 1mm but DO NOT change the conditions on the PHA. The use this spectra to calibrate the spectra for the closed source and hence to obtain the real energy loss as a function of pressure.

Fig. 3 shows a typical ^{241}Am (open emitter) pulse height spectrum. In this measurement amplification has been set such that the peak at U(^{241}Am) = 7.30 V is equivalent to 5.486 MeV, i.e. 1 Volt is equivalent to 0.75 MeV.

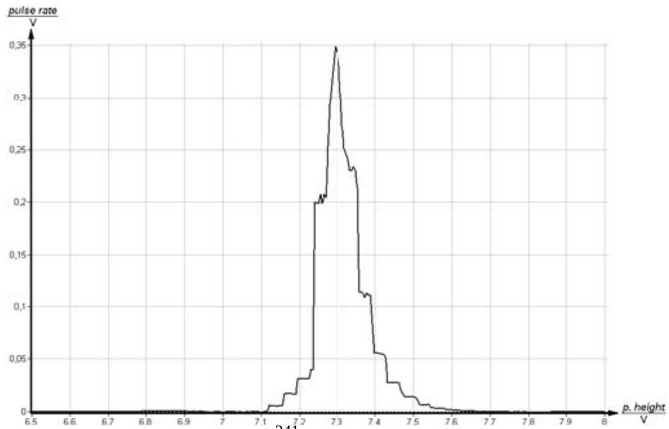

Fig. 3: Calibration measurement with open ^{241}Americium source (E = 5.486 MeV).

Theory

α particles undergo various interactions during their passage through material. One possibility is that of scattering on contact with atomic nuclei. These elastic Rutherford scattering processes, in which the α particles suffer virtually no energy losses, are extremely rare in relation on their inelastic interactions with atoms. These inelastic collisions cause ionization of the atoms, i.e. the α particles loses a small proportion of their energy to an electron in the atomic shell. The mean energy loss per collision in air is 33.7 eV. The frequency of such collisions and in consequence the energy loss per unit of length is a function of the electron density in the absorber material and of the energy of the α particles. The slower the speed of movement of the α particles along their path, the more likely are interactions to occur with shell electrons, giving rise to an increase in the differential energy loss and a decrease in particle energy.

You should use equation 2 to convert your pressures to an effective distance *x* and then plot the mean energy of the α particles as a function of *x*, see figure 4 . You should then calculate the differential energy loss *(-dE/dx)* and plot this as a function of *x*, see figure 5. You should see an increase in the differential energy loss as the particle approaches the end of its path.

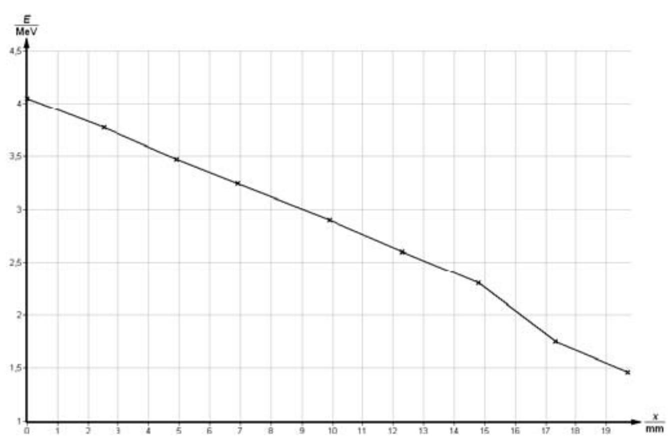

Fig. 5: Mean energy of α particles as a function of *x*.

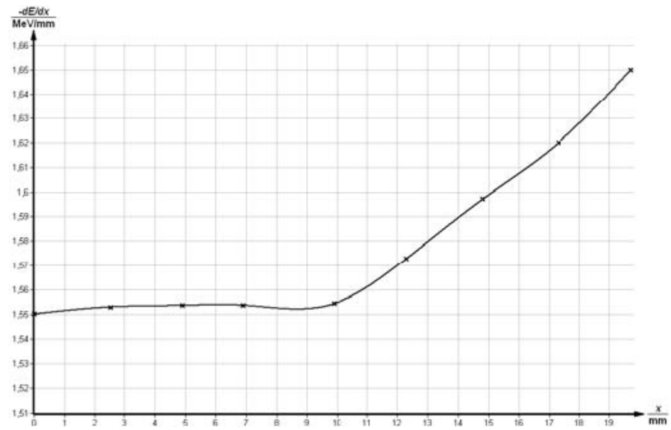

Fig. 6: Differential energy loss –*dE/dx* of α particles as a function of *x*.

The probability of an electron colliding with an α particle is proportional to the electron density in the absorbent gas. At identical pressures and temperatures this electron density in different gases follows the same behaviour pattern as the electron number *N* in the gas molecules.

N is equal to the atomic number of the atom in question and, in the case of molecules, to the sum of the atomic numbers of the atoms contained in the molecule. Fig. 4 shows an example of a measurement carried out at two different pressure values *p*.

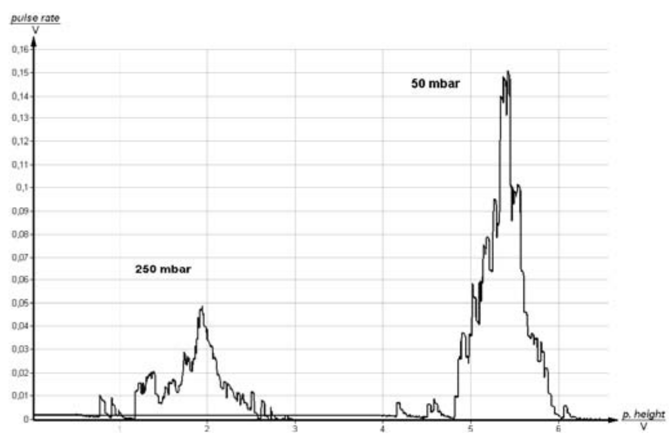

Fig. 4: Pulse rate measurements for different pressure values.

It is to be noted that the differential energy loss of the α particle decreases toward the end of its path as described by the Bethe formula:

$$\frac{dE}{dx} = \frac{nZz_i^2 e^4}{4\pi\varepsilon_0^2 m_0 v_\alpha^2} \ln\left(\frac{2m_0 v_\alpha^2}{E}\right) \tag{3}$$

where *n* = atomic concentration in the retarding material, *Z* = atomic number of the atoms in the retarding material, z_i = atomic number of the charged particles (z_i = 2 for α particles), e = elementary charge, m_0 = electric mass, v_α = velocity of the α particles, E = mean ionization potential. This connection between the differential energy loss and the α particles velocity is shown in diagrammatic form in Fig. 5. The present experiment provides confirmation of this relationship only for the velocity range above the peak of the function shown in Fig. 5. The extremely low velocity range, in which the differential energy loss value again decreases, cannot be recorded with the semi-conductor detector as result of the noise produced by the measuring device.

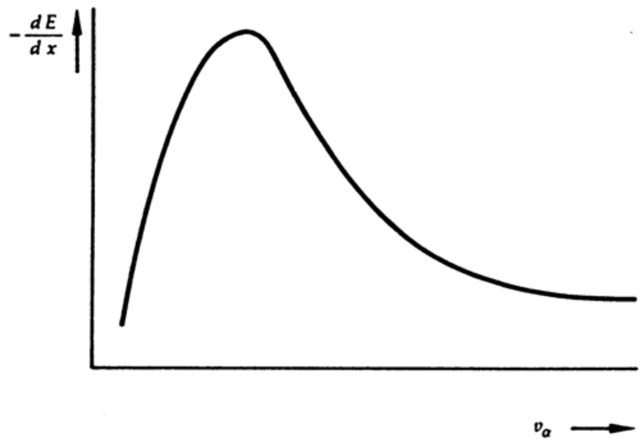

Fig. 7: Theoretical curve for the energy loss of α particles as a function of their velocity.