IIA6

Alpha Energy

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1.1 Preliminary Questions

- Explain the α-decay in your own words.

- Explain the terms decays rate and half life.

- What is the Bethe-Bloch formula and from which parameters does it depend on?

- How can α-particles be screened?

- An alpha detector is a semiconductor detector. Explain how it functions.

1.2 Theory

1.2.1 α Radiation

Radiation can basically take three different forms. In this experiment, it goes as α-radiation. It describes no radiation in the electromagnetic sense, rather than the emission of particles. In other words, α-particles are ionized helium atoms; helium nuclei. Such a nuclei is a highly bound system consisting of two protons and two neutrons. α decays can be written in the following form:

$$(Z, A) \rightarrow (Z - 2, A - 4) + \alpha \tag{1.1}$$

Here Z is the atomic number (number of protons) and A is the mass number (sum of the neutrons and protons) of the parent nucleus.
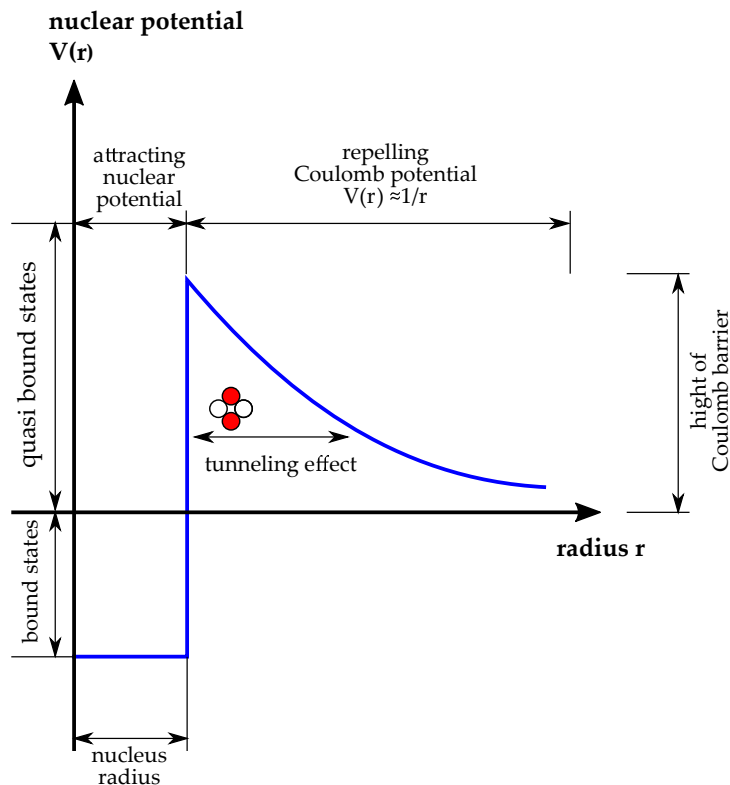

Figure 1.1: Development of the nuclear potential with the Coulomb barrier

The individual nucleons (protons and neutrons) are held together in a nucleus by the strong force (also known as nuclear energy), which is only effective at short distances. On the other hand, the electromagnetic force produces a mutual repulsion of the protons. A nuclei is stable when the electromagnetic force can be compensated by the nuclear power. In the most stable nuclei, there are about as many neutrons as protons. The electromagnetic force acts between all protons in the nucleus, but the nuclear energy has such a short range that it acts only between direct neighboring nucleons. This leads to the fact that heavy nuclei (large atomic number Z) have more neutrons than protons. This produces an imbalance inside the mother nucleus that can build an energetic favorable system of a helium nucleus. Uranium has the atomic number $Z = 92$ and is the heaviest naturally occurring element.

A helium nucleus is formed inside the parent nucleus, so it must possess a certain kinetic energy to leave the attractive nuclear potential and arrive at the Coulomb potential. Viewed classically, the α particles do not have enough kinetic energy to overcome this potential barrier. Nevertheless, that it is possible and can be explained by the quantum tunneling effect. This means removing the α particles with a certain probability to break through this potential barrier. This means that the classical energy conservation may be in the short term violated. This is described by the famous Heisenberg uncertainty principle. How large the probability of tunneling is depends on the kinetic energy of the α particle. The higher the energy, the greater the probability. Therefore, α particles have a discrete energy spectrum between 4 - 6 MeV depending on the source. Achieving an α particle in the mother nucleus with sufficient kinetic energy so it can make it with a certain exit probability. This tunneling probability is proportional to decay rate λ and hence, the half-life.

The fact that there is a relationship between the energy and the rate of decomposition of α emitters was first described in 1911 by Hans Geiger and John Mitchell Nuttall. They formulated the connection with the following empirical formula:

$$ln(\lambda) = -a \cdot \frac{Z}{\sqrt{E}} + b, \tag{1.2}$$

where a and b are parameters to be determined. In quantum mechanics, the α decay was explained for the first time by George Gamow and Walter Gordon in the 20th century.

1.2.2 Interaction of α particles with materiel

Alpha particles have, due to their relatively large mass and charge, a very short distance in penetrating matter. In air, it is only a few centimeters. The biggest energy loss experienced by the α particles is caused by inelastic collisions with the electrons of the surrounding matter. The link between energy loss and penetration depth can be described by the Bethe-Bloch formula. However, the energy loss is not constant, but depends on the instantaneous kinetic energy of the particle. With decreasing kinetic energy, the α particles deposit more and more energy until they finally lose a maximum energy and come to a stop (see Figure 1.2). Then if it is possible, free electrons are catch and thus become helium atoms. The maximum energy loss is called the Bragg peak (after William Henry Bragg). α particles (and also heavier ions) have a very narrow Bragg peak. That means they can almost deposit all their kinetic energy in one place. This property is used in the tumor treatment. The energy of the beam is adjusted so that most of the energy in the tumor tissue is unnecessarily burdened without sacrificing the overlying tissue.
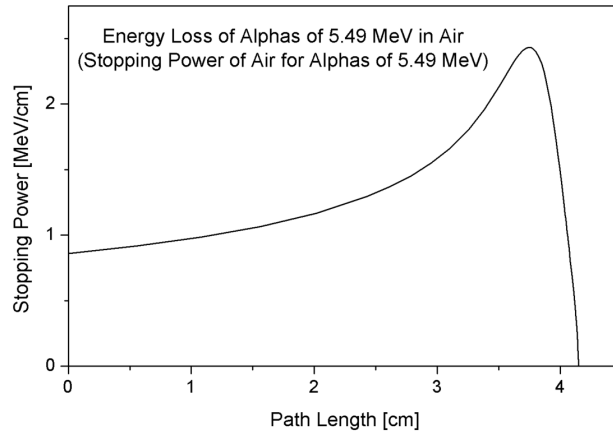
Figure 1.2: Bragg peak of α particles in air

1.3 Experiment

1.3.1 Equipment

Components	Number
Multi-channel analyzer (MCA)	1
Preamplifier for Alpha-Detector	1
Alpha-Detector	1
Mounting plate with markings	1
Detector holder on a fixed magnet	1
Compound holder on a fixed magnet	1
Shielded BNC cable	2
Americium source ($^{241}_{95}$Am)	1
Radium source ($^{226}_{88}$Ra)	1

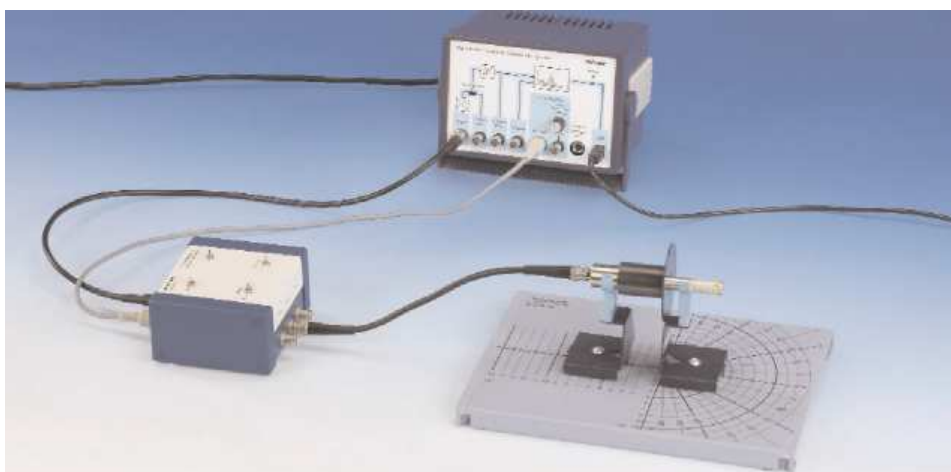### 1.3.2 Experiment Setup and Adjustment

Figure 1.3: Schematic of the experimental setup

1. Connect the preamplifier and the alpha detector with the MCA as shown on Figure 1.3. Make sure the "Input Select" switch is set on to "Input" and not "external input".

2. With the preamplifier, the following settings must be made:

   - Put switch "α/β" to position "α". This is set for the right energy of α particles set.
   - Put switch "inv." from position "Inv." Thus, the negative signal from the detector is inverted.
   - Put switch "bias" from position "Int.". Thus, the bias voltage of the detector set to 12V.
   - Put switch "Bias Int." in position "-". Thus, the polarization of the bias voltage is set. Important: Incorrect polarization can destroy the detector!!

3. Switch the MCA on.

1.3.3 Working with radiative sources

To carry out the test you need radioactive sources. For security reasons, they are stored in a special cabinet. They will be provided by your assistant. After performing the experiment, the sources have to be put back to the special cabinet! As always, when working with radioactive sources (this also applies to weak sources), there are three basic rules:

1. The sources are covered with a thin gold-palladium layer. Thus, the α particles can emerge when it is only a few μm thick. Beware of this! Not even with a pencil or something similar.

2. Do not drink (or smoke) near the radioactive sources. Radioactive substances inside the body can cause serious damage!

3. When you have completed your work with the sources or you are taking a break, always wash your hands well with soap.

If you follow this principle, you are in no danger from these sources.

1.3.4 Implementation

1. Perform calibration:

   (a) Put the radium source all the way into the detector tube.
   (b) Start the computer and open the program "measure".
   (c) Under "measuring machine", choose "MCA" and then "settings and calibration".
   (d) Select "Calibration".
   (e) Select "2-point calibration".
   (f) Select the offset 0% and the gain 2.
   (g) Shift the first (blue) line to the beginning of the spectrum; at the beginning of the exponentially decreasing noise.
   (h) Select the energy value of 0 keV.
   (i) Shift now the second (green) line to the center of the last distinctive peaks.
   (j) Select the energy value 7868 keV.
   (k) Click on "Apply" and then "Save".

(l) Please provide a meaningful name and description for your calibration and save it.

2. Record a spectrum of Americium and Radium:

   (a) Put the source all the way into the detector tube.

   (b) Click on the record button ⏺ and then "'Spectrum recording"'.

   (c) Select the gain of 2 and an offset of 2%.

   (d) In "'X-Datensatz"', select an energy and for "'Intervallbreite"' 50.

   (e) Click on "Reset" and let your measurement run for approximately 10 minutes.

   (f) Click on "'Daten übernehmen"'.

   (g) Store your range and repeat the process with the other sample.

   (h) Tip: with Ctrl-C, you can export your spectrum as either numerical values or as a picture.

3. Determine the range of α particles:

   (a) Attach the source in the holder and bring them up to the stop in the detector.

   (b) Shift both holders and the detector holder on the setup plate so that they are located exactly on one of the markers. The source should now be stuck to the stop detector tubes. The radioactive substances are 7 mm behind the front edge of the source. This edge may be brought to the detector surface to within 1 mm. The minimum distance from the substance to the detector is 8 mm.

   (c) Record a spectrum with 1000 counts.

   (d) Smooth your spectrum ⬍ and run a peak Analysis 📊.

   (e) Write down the positions of the energy maxima and the distance from the source to the detector.

   (f) Move the detector to 5 mm and repeat the measurement until the next marker.

   (g) Increase the separation as long as there are no more pulses in the spectrum. If not, the source is located in the detector tube, you need to cover the source and detector with a cloth, so that no light can disturb your measurement.

   (h) Repeat the measurement with the other source.

1.3.5   Tasks for Evaluation

Decay Series

Create a decay scheme of $^{241}_{95}$Am and $^{226}_{88}$Ra. Give the energy and half-life of the α decays. Which stable isotope forms the decay chains? About the possible decays you find more info from below:

- http://nucleardata.nuclear.lu.se/toi/nucSearch.asp

- http://atom.kaeri.re.kr/nuchart/

Interpretation of the Spectrum

Interpret the recorded spectra of $^{241}_{95}$Am and $^{226}_{88}$Ra. Which peaks are recognizable and from which isotopes are they from? Why is only one peak in the range of $^{241}_{95}$Am recognizable?

Geiger-Nuttall Law

Calculate λ and plot $ln(\lambda)$ versus $\frac{Z}{\sqrt{E}}$ with the peaks from the $^{226}_{88}$Ra spectrum.

Put a linear fit through your readings and determine a and b of the Eq 1.2.

Now plot the peak of the $^{241}_{95}$Am spectrum to it. Are they on the fit?

Calculate the half-life of $^{249}_{98}$Cf with $E_\alpha = 5813.3$ keV and $^{238}_{94}$Pu mit $E_\alpha = 5499.03$ keV and compare them with the literature values.

Range of α particles

Create a Bragg-Plot for both sources. Complete each as follows:

- Compute $\frac{dE}{dx}$ according to the following formula:

$$\frac{dE}{dx} \approx \frac{\Delta E}{\Delta x} = \frac{E_i - E_{i+1}}{d_{i+1} - d_i} \tag{1.3}$$

  Here, E_i is the peak energy of the i-th measurement and d_i is the distance from the detector Source in the i-th measurement. Find now the calculated $\frac{dE}{dx}$ against the mean of distance of the i-th and (i + 1)-th measurement.

- Find now the theoretical values âĂŃof your $\frac{dE}{dx}$ readings by the Bethe-Bloch formula. The non-relativistic Bethe-Bloch formula for α particles in air can be reasonably approximated with the following example:

$$\frac{dE}{dx} = \frac{a}{E[keV]} \cdot (ln(b \cdot E[keV]) - c) \tag{1.4}$$

  where: $a = 1.491 \cdot 10^3 \left[\frac{MeV}{cm} \cdot keV\right]$, $b = 6.35 \cdot 10^{-3} \left[keV^{-1}\right]$, and $c = 0.1241$. Compare the calculated values with the theoretical values.

1.4 Literature

- Povh, Rith, Scholz & Zetsche, *Teilchen und Kerne*, Springer

- Wolfgang Demtröder, *Experimentalphysik 3: Kern-, Teilchen- und Astrophysik*, Springer

- William R. Leo, *Techniques for Nuclear and Particle Physics Experiments*, Springer