National Leó Szilárd Physics Competition Final 2026.
Computer Simulation Task
Theoretical Introduction and Tasks

# Measurement of Alpha Radiation Energy and the Activity of a Sample

First of all, we note that this simulation models an alpha spectroscope that is much simpler than a real one. Nevertheless, it is certainly suitable for becoming familiar with some characteristics of alpha-particle detection.

For better understanding the detection process, let us follow how an alpha particle of a given energy is detected.

## *Efficiency and its Determination*

First, let us consider the detector efficiency. Recall that the range of alpha particles is very small (a fraction of a millimeter in solid matter), therefore alpha particles can escape only from the very thin upper layer of a solid sample. Thus, it is unnecessary to prepare thicker samples, and alpha-emitting samples are therefore made very thin.

Although the detector is placed close to the sample (partly so that the air between them does not absorb the emitted alpha particles, and partly so that as many particles emitted in all directions as possible reach the detector), not every emitted particle reaches the detector. Even if we assume that every particle reaching the detector is detected, we still cannot detect all emitted particles.

The ratio of detected particles to the particles emitted by the source is called the **total efficiency** of the detector.

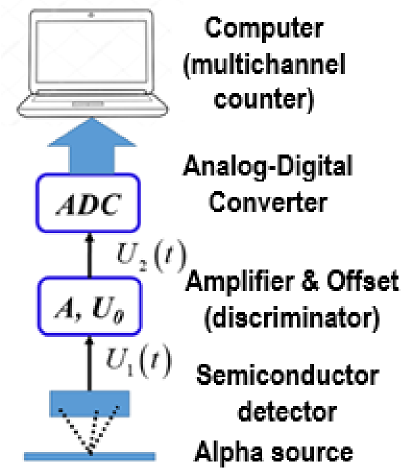
$$\varepsilon_{total} = \frac{\text{number of detected particles}}{\text{number of emitted particles}} \ .$$

This can usually be determined by measuring an alpha source with known activity – a standard source – and observing what fraction of its emissions the detector can detect. The efficiency generally depends on the particle energy, but in our simulation it is independent of energy.

## *Energy and Channel Number*

Since the range of alpha particles is very small, we may reasonably assume that an alpha particle entering the detector is completely stopped and transfers all its energy to the semiconductor detector (essentially, this is a reverse-biased semiconductor diode).
The transferred energy generates a number of charge carriers (electron-hole pairs) in the semiconductor detector proportional to the transferred energy. Their rapid movement inside the detector produces a short current pulse. $I(t) = \dfrac{\Delta Q(t)}{\Delta t}$ .

As this current pulse passes through a resistor, it creates a voltage change – a voltage pulse: $U_1(t) = R \cdot I(t)$ .



This voltage pulse is still rather small, therefore it must be amplified for further processing. At this stage even the zero level of the signal may be shifted by a certain value: $U_2(t) = A \cdot U_1(t) + U_0$ .

Here $A$ denotes the amplification (gain), while $U_0$ denotes the offset value. In order to process the voltage pulse by computer, it must be converted into digital numbers. This is done by an **analog-to-digital converter (ADC)**, which converts voltage pulses within the input range into numbers between 0 and 4096.

Thus, for every detected alpha particle we obtain a number that is linearly related to the particle energy; this is called the **channel number**.

Each channel is a separate counter that counts how many alpha particles were detected within the corresponding narrow energy interval (for example between 4000 and 4002 keV). Therefore, when a particle is detected, the counter corresponding to its energy (channel) increases by one — the histogram of the alpha spectrum is composed of the contents of these channels.

Unfortunately, we usually do not know exactly what transformations occur before the particle energy becomes a channel number. However, we may assume that the linear relationship between particle energy $(E)$ and channel number $(C)$ is preserved: $E = a \cdot C + b$.

To determine the particle energy from the measured channel numbers, the constants $a$ and $b$ must be determined. This can be done by measuring alpha radiations of at least two — preferably several — known energies and determining into which channels they fall.

In the simulation, we can use the $^{238}$U / $^{234}$U sample in radioactive equilibrium (standard sample), since the energies of the alpha radiation they emit can be looked up in the table accessible through the program menu item "***Alpha Energies***".

## *Dead Time and Live Time*

Even a fast electronic circuit (or a computer) requires time to analyze and process the pulses coming from the detector. During this time the instrument cannot accept the pulse of another particle. This is called the ***dead time***.

Suppose the processing of every particle takes a time $\tau$, which is the dead time.

If the instrument detects $N$ particles during a time interval $T$, then the instrument was "dead" for a total time of $N \cdot \tau$. Therefore, the ***live time*** is: $T_{live} = T - N \cdot \tau$.

The measured count number was obtained during this live time, therefore the count rate is:

$$n_{real} = \frac{N}{T_{live}} = \frac{N}{T - N \cdot \tau} = \frac{N/T}{1 - \tau \cdot (N/T)} = \frac{n_{measured}}{1 - n_{measured} \cdot \tau}$$

. Here we used $n_{measured} = \frac{N}{T}$ the measured count rate. The relationship between $n_{real}$ and $n_{measured}$ is called ***dead-time correction***.

It can be calculated from the measured count rate, if the dead time is known.
In some instruments the dead time also depends on the particle energy, which makes data processing even more complicated. In our simulation program the dead time is fixed, and it can be determined using the live time shown by the program.

## Tasks

### Task 1 (0 points)

- Become familiar with the program! (See the separate program user guide.) Examine how the individual controls operate.

### Task 2 (4 points)

- Investigate the low-energy electronic noise at amplification 50 without a radiation source! Try to determine according to what function the intensity of the electronic noise changes as a function of pulse amplitude (channel number).
- Define a ROI (see the program guide) that includes all counts originating from noise. Determine the dead time from the measured count number and the live time displayed by the program! (Save the screen for the jury.)
- Examine the effect of the helical potentiometer controlled by the circular knob! Try to adjust it so that the electronic noise is not disturbingly large.

## Task 3 (8 points)

- Become familiar with the “***Alpha Energies***” table! Consider what the data in the different columns may represent and how they appear in the spectrum.
- To determine the energy calibration and efficiency, select the $^{238}$U / $^{234}$U standard sample! Describe in the report what it means that the sample is in **secular equilibrium**.
- Using quick “sample measurements,” determine what amplification can and should be used during longer measurements. Check whether this setting will also be suitable for the measurement of the unknown sample! Justify the decision in the report! Also ensure that the electronic noise is not disturbing. (If necessary, modify the discriminator setting.) Be careful not to change the amplification and discriminator parameters later!
- Record the alpha spectrum of the uranium sample for a sufficiently long time to reduce statistical uncertainties, and try to assign the measured peaks to the alpha energies listed in the table! (Save the screen for the jury.)
- Plot the alpha-energy values as a function of the obtained channel numbers and fit a straight line to them! Record the $E = a \cdot C + b$ equation of the fitted line and the parameters $a$ and $b$! It is recommended to use EXCEL available on the computer, although graph paper may also be used. If working on the computer, save the Excel file for the jury in the folder marked with your code number.

## Task 4 (2 points)

- Knowing that the activity of $^{238}$U in the uranium sample is exactly 10 kBq, determine the total efficiency of the alpha spectroscope!

## Task 5 (8 points)

- Select the unknown sample and record its spectrum! (Save the screen for the jury.)
- Using the previously determined constants $a$ and $b$, determine the energies corresponding to the peaks found in the spectrum! Based on the energies, try to identify which alpha-decaying nuclides may be present in the unknown sample.
- Using the known efficiency of the spectroscope, determine the activity of each atomic species!

## Task 6 (3 points)

- **Document** your work, write down your thoughts and the results in the report!