# Radioactive decay

*Aim of the experiment:* determination of background radiation, determination of absorption of radioactive radiation.

*Instruments:* computer system with interface, sensor of ionising radiation, weak radioactive source.

*Problem:* radioactivity

References: S5.2 (69-86), JD3 (17), HS (29.0, 29.1), statistical distribution of results of measurements HS (1.3).

## 1. Introduction

Ionising radiation induces ionisation of the medium in which it propagates. Such properties show X-ray radiation, radioactive radiation $\alpha$, $\beta$, $\gamma$ and electromagnetic radiation in the near ultraviolet range. Energy of ionising radiation is measured in joules (J). To facilitate the description of the phenomenon, some additional physical quantities are introduced:

**Radioactive activity of a source** *A* is defined as the number of decays per second:

$$A = -\frac{dN(t)}{dt} = \lambda N(t) \tag{1}$$

where $N(t)$ is the number of atomic nuclei of radioactive material that have not decayed at time $t$, while $\lambda$ is the radioactive decay constant describing how many nuclei undergo decay in a unit of time, so describing the rate of radioactive decay. Radioactive activity is expressed in becquerels (Bq) (1 Bq = 1 decay per 1 second) or in Curies Ci (1 Ci = $3.7 \cdot 10^{10}$ decays per 1 second = $3.7 \cdot 10^{10}$ Bq).

**Exposition dose** is a measure of the ionising radiation ability to ionise the air through which it passes. The unit of exposition dose is roentgen (R); one roentgen is defined as the dose

which provides 8.78 mJ of energy to 1 kg of dry air in normal conditions. Earlier one roentgen was defined as the dose which in 1 cm$^3$ of dry air in normal conditions generates ions of each sign of the total charge equal to one electrostatic unit. The exposition dose describes the energy lost by ionising radiation and not the dose of energy absorbed by the medium.

**Absorbed dose** – the dose of radiation absorbed by a certain medium is measured in greys (Gy). The absorbed energy is equal to 1 Gy, if 1 kg of the medium absorbs the energy of 1 J. There is another unit still in use, roentgen defined as 1 R = 0.01 Gy.

In medicine and biology it is convenient to use the **equivalent of exposition dose** or **equivalent dose** expressed in sieverts (Sv). Equivalent dose is a dose quantity used in radiological protection to represent the stochastic health effects (probability of cancer induction and genetic damage) of low levels of ionising radiation on the human body. It is based on the physical quantity absorbed dose, but takes into account the biological effectiveness of the radiation, which is dependent on the radiation type and energy. To calculate equivalent dose the dose expressed in greys is multiplied by coefficients of relative biological effectiveness. The coefficients are tabulated, for gamma irradiation and electrons they are close to one, for alpha irradiation this coefficient is close to 10. There is also another not SI unit in use 1 REM = 0.01 Sv.

The activity of the source used in the experiment you are going to perform is so low that it has no effect on the experimenter health.

## 2. Experiment

To perform the experiment you need a Geiger – Müller counter (G-M), voltmeter, a connector box interfacing the G-M counter with an acquisition card plugged into a PC and a program working in LabView environment. The sensor comprising a G-M counter is in a special case with connections to the connector box. The G-M counter is mounted in the front of the case and its cross-section area is close to 1.5 cm$^2$. Behind it there is a potentiometer regulating the supply voltage in the range from 300 V to 800 V. On the right hand side there is a potentiometer knob, while on the left hand side there is a terminal permitting a connection with a voltmeter of very high input resistance. The G-M counter is adapted for measurements of β and γ radiation.

**Determination of Geiger – Müller characteristic.** The sensitivity of a G-M counter

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Eksperymentu Fizycznego

Fizyczne Laboratorium Mikrokomputerowe
Filami

Wydział Fizyki
UAM

depends on the voltage applied to it, that is why it is necessary to start with determination of the working voltage for which the counter sensitivity is the highest. To do this, the sensor must be connected to the acquisition card through the connector box. At a distance of a few centimetres from the front wall of the sensor, place a source of radiation of very small activity. Then, you should start the program "Badanie rozpadu promieniotwórczego" [a study of radioactive decay] available on the computer desktop and then choose the tab : G-M counter characteristics (Fig. 1).
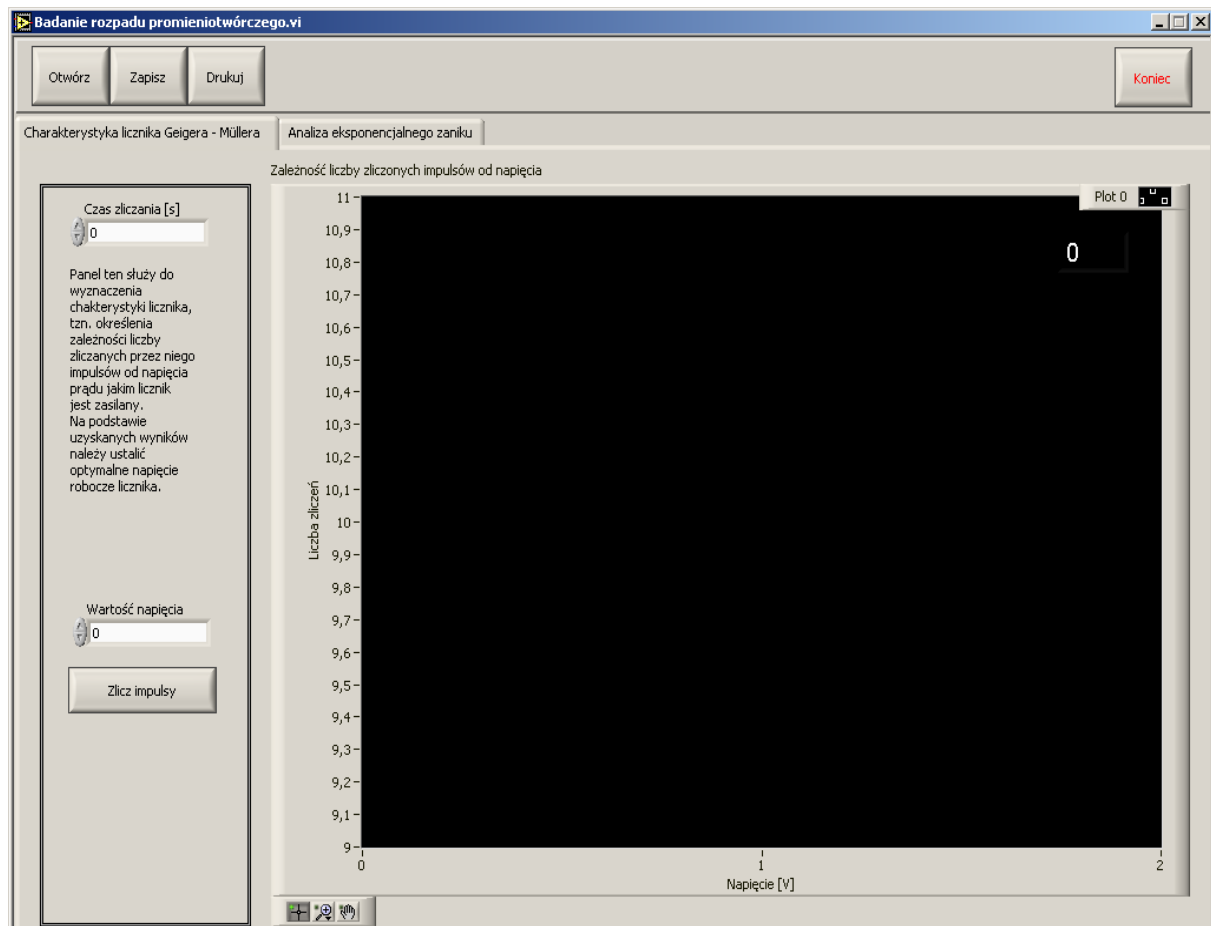


**Figure 1.** The screen view of the program "Badanie rozpadu promieniotwórczego" [a study of radioactive decay], the part needed for determination of the Geiger – Müller counter characteristics.

In the box "Czas zliczania" [time of counting] you should introduce time of counting e.g. 1 minute in which you want to count the pulses of radiation in a certain step of measurements. Connect the voltmeter to the sensor. With the help of the potentiometer mounted in the back of the sensor, change the voltage supplied over the range available. Write the value of voltage read on the voltmeter in the appropriate box on the computer screen. Start the measurement by pressing the button "Zlicz impulsy" [count the pulses]. The data are collected

by the program, which presents them graphically on a plot. Make 3 measurements for each value of voltage. In the next step change the voltage value and repeat the measurement. On the basis of the plot you should establish the working voltage and set it by the potentiometer.

**Distribution of the number of pulses recorded in stable conditions.** Having set the working voltage, place the source of radiation at such a distance from the sensor to get the number of counts in a certain period of time (e.g. 1 minute) smaller than 20. Now, record the number of counts for over 100 times and then analyse the statistical distribution of the results as shown in Section 1.3 of the book *Pracownia Fizyczna*.

**Determination of damping of ionising radiation.** On passing through matter the ionising radiation is weakened because of the loss of the energy used for ionisation. The intensity of radiation beam *I*, after passing through the active medium layer of the thickness *d*, exponentially decreases according to the expression:

$$I = I_0 e^{-\mu d}, \tag{2}$$

where $I_0$ stands for the initial intensity of the beam prior to entering the active medium (absorbent) and $\mu$ is the linear coefficient of damping, depending on the composition of the medium and on the energy of the radiation. The ability of a given medium [material] to absorb and scatter ionising radiation is characterised by the damping coefficient. The damping of radiation is often characterised by another parameter, the so-called half-value layer (HVL) or half-value thickness $d_{1/2}$. It is the thickness of the material at which the intensity of radiation entering it is reduced by one half. The half-value thickness can be obtained from the equation (2):

$$\frac{I_0}{2} = I_0 e^{-\mu d_{1/2}} \tag{3}$$

equivalent to

$$d_{1/2} = \frac{1}{\mu} \ln 2 \tag{4}$$

The aim of the next experiment is determination of the half-value thickness of aluminium or the decay constant of the decaying quantity. In this part of measurements use the tab "Analiza eksponencjalnego zaniku" [analysis of exponential decay] shown in Fig. 2.
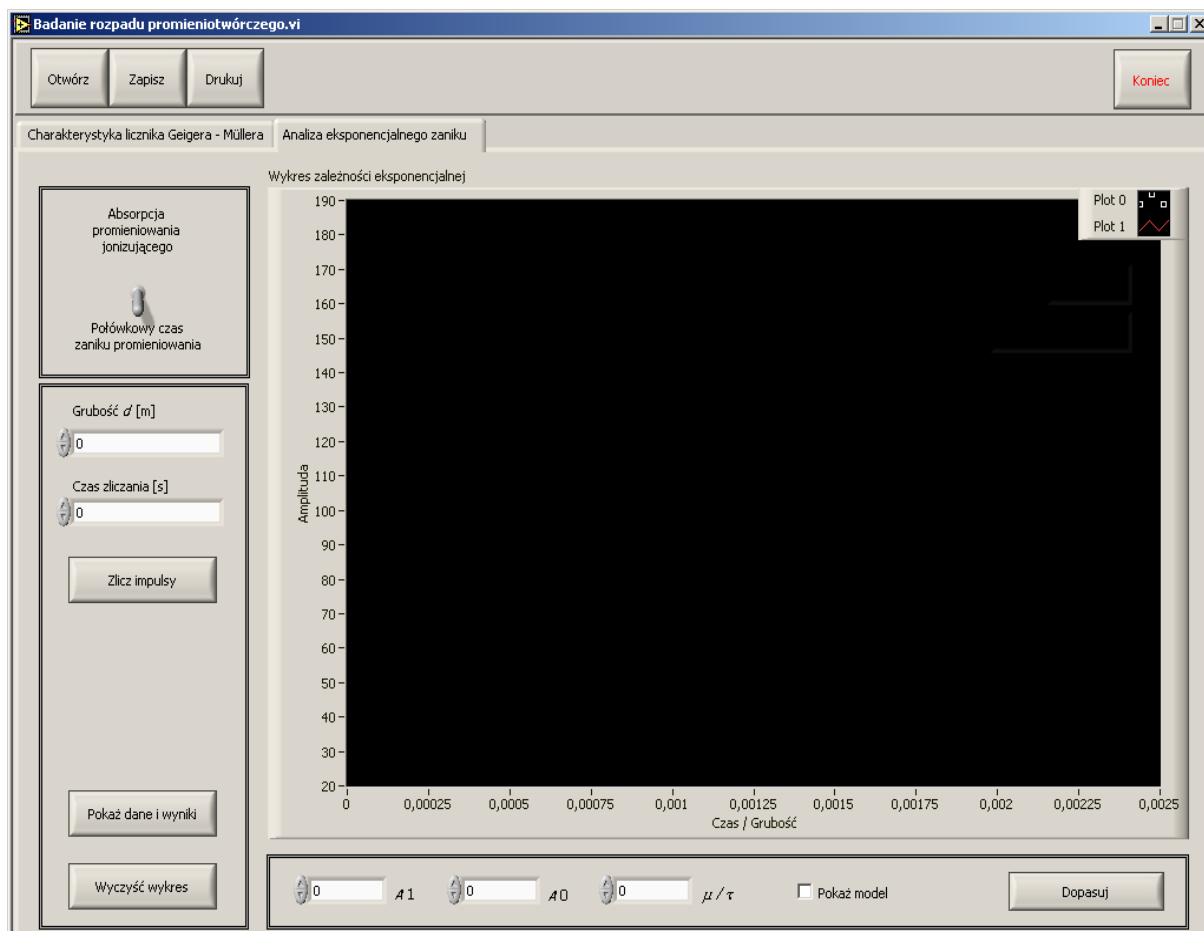
**Figure. 2.** View of computer screen for determination of the half-value thickness of an
active medium or its half-value decay time.

In the upper tab switch to "Absorpcja promieniowania jonizującego" [absorption of ionising
radiation]. In the box "Czas zliczania" write the time of pulse counting in subsequent
measurements (e.g. 100 s). Place a certain layer of studied material between the source and the G-M
counter. Enter its thickness (in [m]) in the editing window "Grubość d" [thickness d]. By pressing the
button "Zlicz impulsy" [count pulses] the process of counting the pulses for a given sample starts.
Repeat this procedure for a series of samples of different thicknesses.

The data collected can be analysed with the help of the tool-panel below the screen.
By marking the option "Pokaż model" [show the model] the plot of the following function is
displayed on the screen:

$$y = A_1 + A_0 e^{-d\mu} \tag{5}$$

Changes in the parameters $A_1$, $A_0$ and $\mu$, result in a dynamic change in the course of the line displayed. Select the most suitable parameters and start the process of fitting the function by pressing the button "Dopasuj" [adjust]. The procedure of fitting the function to the data is based on the Levenberg-Marquardt algorithm and ends with getting the best fit parameters displayed in the boxes of parameters. On the basis of the best fit parameters the value $d_{1/2}$ is calculated. To see the experimental data and best fit parameters press the button "Pokaż dane i wyniki" [display data and results].

Press the button "Wyczyść wykres" [erase the plot] to remove the plot and remove the data from memory. The buttons "Otwórz" [open], "Zapisz" [write] and "Drukuj" [print] start the respective processes.