Z31 - Rutherford Experiment

Physics Laboratory II
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The purpose of this experiment is to repeat the Rutherford gold foil experiment, i.e. to measure relation between the number of scattered on a thin gold foil α particles and their scattering angle.

Preparatory questions

- α particles – structure, creation, basic features [1, 2].
- α decay – basic features, in particular selection rules [1, 2].
- Interaction of α particles with matter – in particular the Rutherford scattering (formula) [1, 2].
- Detection mechanism of semiconductor silicon detectors [1, 2].

  Before commencing the exercise it is necessary to read the full version of this instruction (available after logging to the web page of the 2nd Physical Laboratory).

Computational assignments

Using formulas from the full version of this instruction calculate how much will the number of incident on the detector alpha particles change if the source-detector distance will increase from 5 to 19 cm.

Apparatus and materials

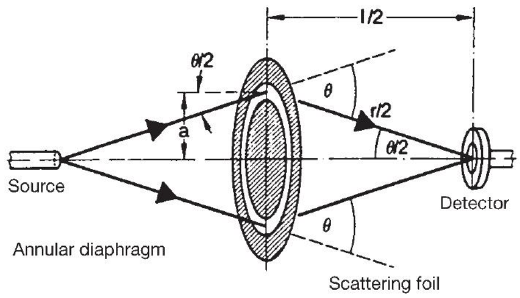
Experimental set-up is shown on the Fig 1. It consists of:

1. Vacuum chamber with a mounted silicon detector. The chamber can be opened from both sides.
2. Closed source of α particles: ^{241}Am.
3. Gold and aluminium foils and a magnet (not visible on the picture). The foils are mounted on frames which can be moved inside the vacuum chamber with the magnet.
4. Pressure gauge.
5. Vacuum pump.
6. Preamplifier.
7. Multichannel analyser (AWK) with a „measure" application installed on the PC.

Experiment

Plan details are given in the full version of the instruction.

1. Starting up of the apparatus.
2. Measurement of forward scattering of α particles on a gold foil.



   After installation of the gold foil, the vacuum chamber is pumped out to pressure below $20hPa$. The measurement should be repeated for several distances between the source and the detector, e.g. for l=5,7,10,14 and 19 cm. Each time the foil must be placed in the middle, in $l/2$ distance from the detector.

   - You must not touch the foil with nothing, in particular with your fingers.
   - The source should be moved by simultaneous delicate turning and pushing or pulling the rod, on which the source is mounted.
   - The foil position can be changed by delicate moving the dedicated magnet, which you should place on the table, below the vacuum chamber.
   - If the positions of both the source and the foil are set you should shield the vacuum chamber from the ambient light. You can start the measurement now. You should keep the results (number of registered particles as a function of the detector-source distance) up to date in your log-book. Do not trust the "measure" software.

3. Change the gold foil with aluminium foil and perform one, 2400s-long measurement for $l = 10cm$.

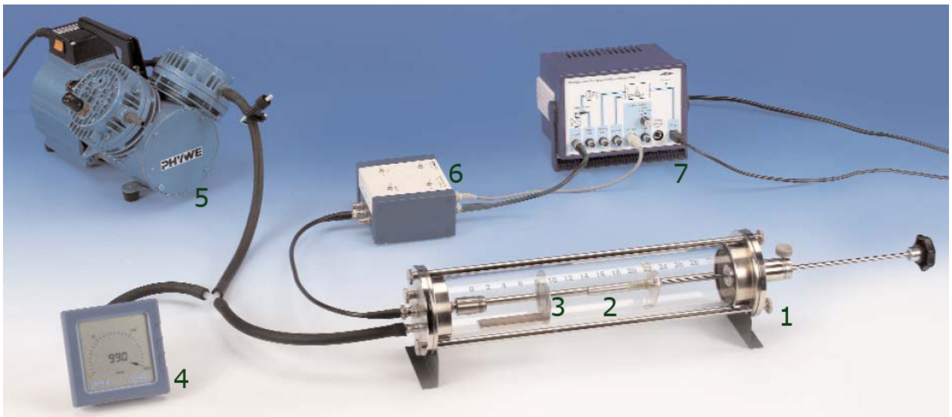
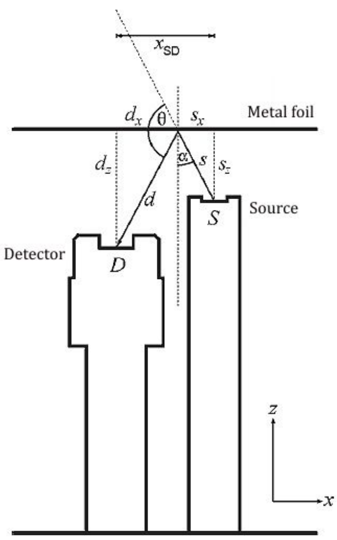


Figure 1: Experimental setup

4. Because the detector registers not only alpha particles scattered directly on the foil but also particles scattered on the glass housing and other particles (so-called background) it is useful to perform the background measurement. First, one can perform measurement with empty frame (without any foil). Second, you can repeat the measurement with the gold foil but with empty frame placed ca 5 mm apart from the gold foil on the detector side – in this way the empty frame plays a role of an collimator which decreases influence of particles scattered on the vacuum chamber housing. In this case, you will have to take into account decrease of the sold angle of the detector.



5. Next, one can perform measurement of the backward scattering of alpha particles on the foil. To this aim you should mount the source on the same flange as a detector (as in the drawing on the right) – the foil is facing both the detector and the source. The measurement should be performed for several foil-source distances, e.g. Sz = 4.0, 4.5, 5.0, 5.5 and 6.0 cm. The measurement can be repeated with the aluminium foil for Sz = 4.0 cm.

Data analysis

The details can be found in the full version of this instruction.

1. Evaluation of results for the forward scattering measurement:

   - Using formulas given in the full version of the instruction, calculate expected rate of registered particles (per second)assuming that $E\alpha = 3MeV$, $a = 20.16mm$, $Q = 370kBq$, $AF = 6cm^2$, $dF = 1.5\mu m$, and $AD = 45mm^2$ – Please, present a table and a plot containing both measured and calculated values. Are these values in agreement?
   - Compare results obtained with and without empty frame (in case such measurements have been performed). What is the meaning of empty frame measurement? Estimate, which part of particles was able to pass through the empty frame, when the frame was placed 5 mm from the gold foil.
   - Compare measurements performed with the gold and the aluminium foil for the same source – detector distance l.
   - The listed in point i. energy of α particles is approximate. You can estimate this value more accurately assuming that the thickness of the ^{241}Am source is protected by the 5 μm–thick gold foil. Moreover, α particles can scatter on different depths of the target foil (mounted on the frame). As a result, energy of the α particles during scattering depends on the scattering depth as well. How can you take this effect into account in your calculations?
   - Estimate both statistical and systematic uncertainties of this measurement.

2. Evaluation of results for the backward scattering measurement:

- The main problem of this measurement is lack of collimation – one cannot limit the range of trajectories of α particles. We do not know scattering points of particles registered in the detector. There are two possible approaches to this problem: simplified and accurate.
- In the simplified approach one can use the fact, that the solid angle of detector visible from the scattering point decreases like $\frac{1}{r^2} = \frac{1}{(s+d)^2}$ (see the drawing above) and assume that the main contribution comes from cases where the distance $s + d$ is minimal. In this case, one is not able to obtain full agreement because calculated and measured data because we integrate both area and depth of the foil. Instead, we can compare shape of the dependence between number of scattered particles and the scattering angle. We must use formulas derived in the full version of this instruction.
- Comparison of the measurements with the gold and the aluminium foil should be performed in a similar way.
- Accurate approach to the problem of not collimated trajectories requires integration of the Rutherford formula over the whole area and depth of the foil. It means, that it is necessary to use the Bethe formula to take into account changes of energy of α particles while they penetrate of the gold foil. This calculation is rather complicated and definitely goes beyond the scope of the 2nd Physical Laboratory.

Safety rules

As usual, any work with radioactive sources must be performed with a great caution. Although we use only closed sources, it is not permitted to remove or touch the sources without the presence of an assistant. You must never touch the foil protecting the source, since the foil is fragile and must not be damaged.

References

[1] A. Strzałkowski, *Wstęp do fizyki jądra atomowego*, PWN - Interaction of heavy charged particles with matter and semiconductor detectors (counters) .

[2] Z. Wilhelmi, *Fizyka reakcji jądrowych*, PWN. Rozdział 2.3.1: „Rozpraszanie kulombowskie cząstek α”.