



experiment no. 3.3

Rutherford Scattering

as at March 16, 2015

Abstract

In this experiment the famous experiment of Rutherford, Geiger and Marsden, which lead to the development of the nuclear model, is reproduced. Therefore, α particles emitted by a radioactive source are scattered on a thin foil made of gold, before they are detected in a silicon detector. The refined measurement set-up, invented by Chadwick, allows for a measurement of the angular distribution of the scattered α particles with up to five data points on a single day. Pulse height spectra are recorded, using a combination of an ADC and a PC. After integration of the spectra – and following transformation into the center-of-mass system – the measured intensities are converted into absolute cross sections.

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1 Introduction

Ernest Rutherford and his fellows Geiger and Marsden proved between 1911 and 1913 the existence of the atomic nucleus. Scattering experiments with this character are until nowadays one of the key techniques in nuclear physics.

2 Advice for preparation

(This should be part of your written preparation)

- Historical and actual impact Rutherford's experiment on nuclear structure
- Mechanism of scattering, especially Coulomb scattering
- Cross-section, definition
- Rutherford-Cross-section, ONE derivation (class. or qm.)
- Nuclear potential
- Semiconductor-detectors, especially Surface-barrier-Si-detectors (as used in this experiment) (Other important knowledge for this experiment)
- α decay
- electronic measuring equipment (preamplifier, shaping amplifier, multi channel analyzer)
- Error analysis, statistics

3 Layout of the experiment

In Geiger's and Marsden's original layout, a collimated beam of α particles was impinging on a fixed gold foil. The used detector could be moved on a circular arc around the target. Due to this configuration the detector's solid angle was kept constant. Neglecting any inelastic effect the $\frac{1}{\sin^4(\theta/2)}$ -dependance could be seen directly. Disadvantage of the original layout is its low counting rate. Therefore this experiment uses the geometric layout Chadwick used in 1920 to measure nuclear charges. Geometric means, that the distances foil-detector and foil-source are equal, but can be chosen. It consists of a ring-shaped gold foil as centre part. Figure 2 shows the layout in detail. Detector (D) is fixed positions of foil (F) and source (Q) can be chosen with the slide rod (S). There is also a triple- α -source (E) for energy calibration. Two apertures (A,B) can be used, either to shut the source (Q) or to open the hole in the foil (O) for activity measurement.

The detector is connected to a charge-sensitive-preamplifier, which converts collected charges to a voltage pulse. This is converted to a Gaussian shape by the shaping amplifier. The multi-channel-analyzer creates an energy-like spectrum. The vacuum is in the order of 10^{-1} mbar. Do you expect the energy loss in residual gas to have influence on the experiment? (Why?)

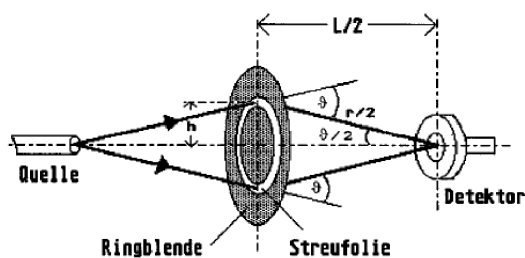


Figure 1: principle of the experiment

4 Experiment's procedure

- Create a folder for your group in /Desktop/praktikum.
- Perform an energy calibration with triple- α source.
- Define the source's (Q) activity, by measuring 10 minutes with opened aperture (B).
- Measure scattering rates at different detector-foil-distances (5, 10, 15, 20, 25 cm) for 45 minutes. Do not forget to fix the foil-source-distance at the same value.

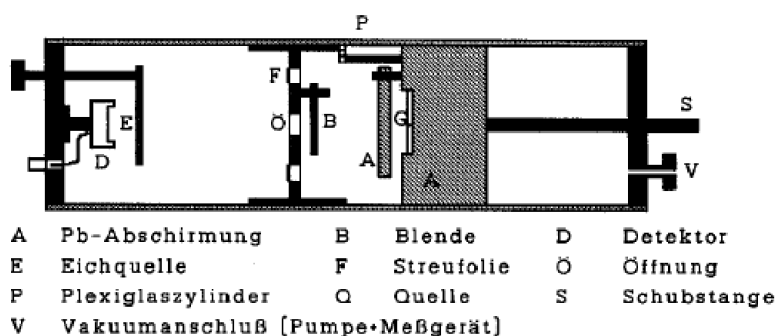


Figure 2: layout

5 The analysis

You should compare theoretical and experimental cross section for each distance. Therefore you have to know average energy of the α particles at the time of scattering and the scattering angle. In which processes do the α particles loose parts of their energy? Due to the not punctual shape of source, detector and foil there will be always a scattering-angle interval (Fig.3). The average scattering angles can be derived in two ways: the arithmetical average between the minimal and maximal angle and integration of the angular dependence of scattering over the interval. Results and errors are of both calculations are given in the appendix. To calculate cross-sections you need the following quantities:

- number of scattered α particles (INTEGRATION over the scattering peak)
- number of impinging α particles (from activity calibration)
- density of scattering centres (proportional to effective thickness of foil)
- solid angle of detector for given distance

You have to correct detector's and foil's area, due to the non-perpendicular entering of particles. Also effective thickness of foil increases. Give a formula for the experimental cross-sections which only depends on directly measurable quantities and constants!

1. Calculate the experimental constant $C_{exp} = \frac{d\sigma}{d\Omega_{exp}} \cdot E^2 \cdot \sin^4\left(\frac{\theta}{2}\right)$ and compare with its theoretical equivalent (graphically and means).

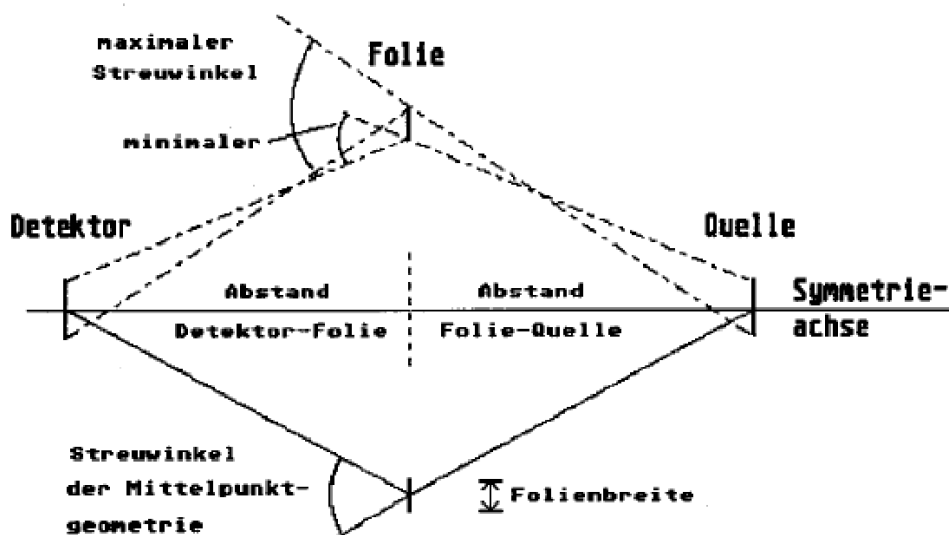


Figure 3: scattering angle

2. Compare experimental and theoretical cross sections (with its errors). Give also a useful graphical illustration.
3. Is it in this case better to compare constants then cross-sections? Why?
4. Discuss discrepancies!

6 Remarks for your analysis

Give an derivation for:

$$\frac{d\sigma}{d\Omega} = \left(\frac{1}{4\pi\epsilon_0} \right)^2 \frac{(zZe^2)^2}{(4E)^2} \frac{1}{\sin^4(\Theta/2)}$$

with

- z = Number of protons in projectile
- Z = Number of protons in target
- e = Elementary charge
- E = Energy of projectile
- Θ = Scattering angle

Which assumptions and simplifications were made in derivation of this formula? In this experiment you should compare theoretical and experimental values of cross-sections. This has to be done in the centre-of-mass-system. (Why?) Therefore you have to transform (give transformation rules!) energies, scattering angles and solid angles.

A Important information for the experiment

- **source:** ^{241}Am , 10mm diameter
energy calibration source:
 - ^{239}Pu : 5.143 MeV, 5.155 MeV.
 - ^{241}Am : 5.389 MeV (very weak), 5.443 MeV, 5.486 MeV.
 - ^{244}Cm : 5.764 MeV, 5.805 MeV.
- **gold foil:**
 - average thickness: $(1.4 \pm 0.1) \mu\text{m}$
 - area: $(5.5 \pm 0.1) \text{cm}^2$
 - outer radius : 28 (1) mm

- innerer radius: 24 (1) mm
- **detector:** diameter: 8 mm, active area: 0.5 cm².
- **high voltage:** + 60V, SHUT DOWN detector before move chamber coverage
- **scattering angles:** detector's position is not at 0 mm of mounted scale!!!

B Operating instructions

Operating instructions for electric powered equipment in the rooms for the practical course

Danger for people

Burns or death by high electric currents

Safety measures:

Pay attention that cables and plugs are not damaged and use them only in the way they are designed for.

In case of damage, or if you have the suspicion that they are damaged inform immediately your supervisor, do not try to repair anything yourself.

Use at maximum one extension cord and only for low powered equipment.

For equipment with large power consumption only wall outlets should be used.

In case of emergency:

Pull the mains plug.

In case of fire: Switch of all electrical equipment as far as possible.

First aid:

People who can give first aid are Görden, Rolke, Rudolph, Thiel

In case of shock call immediately an emergency physician Tel. **01-112** (from any telephone in the institute, or mobile **112**)

Hospital for accidents: evangelisches Krankenhaus Weyertal.

In case of all accidents also the managing director of the institute has to be informed.

In case of a working inability of 3 or more days an accident report form available from the secretary has to be filled.

The first aid box can be found in the inner stairwell.

13/11/2014

Blazhev

Operating instructions for high voltage equipment in the rooms for the practical course

Danger for people

Instantaneous death by ventricular fibrillation

Safety measures:

Pay attention that cables and plugs are not damaged and use them only in the way they are designed for.

In case of damage, or if you have the suspicion that they are damaged inform immediately your supervisor, do not try to repair anything yourself.

Switch on the high tension only after the cables have been connected and switch it off before disconnecting.

In case of emergency:

Switch of the high tension

In case of fire: Switch of all electrical equipment as far as possible

First aid:

People who can give first aid are Görden, Rolke, Rudolph, Thiel

In case of shock call immediately an emergency physician Tel. **01-112** (from any telephone in the institute, or mobile **112**)

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Universität zu Köln	Operating instructions	Nr.: Date: 13.11.2014 Signature: A. Blazhev
for the rooms of the practical course / institute for nuclear physics		
IDENTIFICATION OF SUBSTANCE		
<p>Lead bricks</p> <p>Lead bricks packed in plastic foil can be touched without precautions. They are very heavy, <u>put them only in places where they can not drop on your feet!</u> If the foil is damaged please pay attention to the following instructions:</p>		
DANGER FOR PEOPLE AND ENVIRONMENT		
 <p>Danger</p>  <p>Warning</p>	<p>May cause harm to the unborn child.</p> <p>May cause damage to organs through prolonged or repeated exposure.</p> <p>Very toxic to aquatic life with long lasting effects</p> <p>Do not breathe dust/fumes/gas /mist /vapours/spray</p> <p>Avoid release to the environment</p>	
SAFETY MEASURES AND RULES		
   	<p><u>Do not touch any lead brick with a damaged protective foil. If the foil is damaged or if you suspect that it is damaged please inform immediately your supervisor</u></p> <p>Breathing equipment: In case of fire toxic metal oxide smoke can be released. Wear self contained breathing apparatus.</p> <p>Protective equipment: If the protective foil is damaged, lead brick must be touched only with protective gloves.</p> <p>IN CASE OF ACCIDENT Fire brigade 01-112 from any phone, mobil 112</p> <p>Leave the contaminated area and inform your supervisor. If lead dust has to be removed wear always safety glasses, protective gloves and in case of large quantities a breathing apparatus.</p> <p>Fire extinguishing measures have to be taken according to the surrounding materials. In case of a fire dangerous fumes are generated. Please take actions according to the emergency action plan. Call the fire brigade. Lead must not get in the sewage system.</p>	
FIRST AID		emergency physician 01-112, mobil 112
	<p>After eye contact: Rinse opened eye for several minutes under running water. Then consult doctor.</p> <p>After skin contact: Instantly wash with water and soap and rinse thoroughly.</p> <p>After swallowing: Seek immediate medical advice.</p> <p>After inhalation: Supply fresh air. If required provide artificial respiration. Keep patient warm. Consult doctor if symptoms persist.</p> <p>First aid can provide: Görgen, Rolke, Rudolph, Thiel</p>	
DISPOSAL		
<p>Do not put lead in the sewage or the dust bin. Disposal has to be made via Dr. Blazhev or Bereich 02.2</p>		

Radiation protection directive for the handling of radioactive sources in the practical courses of the Institute of Nuclear Physics of the University of Cologne.

Issued 13/11/2014

1. Admission restrictions

Persons under the age of 18 years are not allowed to work in the practical course.

Pregnant women must not work with radioactive sources or in rooms in which radioactive sources are located.

Only students who have filled the registrations sheet and participated in the radiation protection instructions are allowed to carry out experiments with radioactive sources in the rooms of the practical course under the instruction of a supervisor. Visitors must not enter the rooms of the practical course when radioactive sources are located there.

2. Handling of radioactive sources

The radioactive sources are put in the experimental setup or in the lead shielding nearby by a radiation protection officer or an instructed person before the beginning of the practical course. These people document the issue in the list which is placed in the storage room (see appendix B). If radioactive sources have to be transported to other Physics institutes of the University of Cologne a list according to appendix A has to be attached to the transporting container.

When the practical course is finished the same people bring the radioactive sources back to the storage room.

A sign „Überwachungsbereich, Zutritt für Unbefugte verboten“ which means „monitored in-plant area, admission only for authorized personnel“ has to be attached to the door of a room of the practical course when radioactive sources are inside.

It is not allowed to remove radioactive sources from the rooms of the practical course without contacting the radiation protection officer before.

During the practical course the radioactive sources must only be located at the place necessary for the measurements or behind the lead shielding nearby the experimental setup.

If you leave the rooms of the practical course make certain that doors are locked and windows are closed, even if you only leave for a short time.

Alpha-Sources are built in the experimental setup and students are not allowed to take them out.

Beta-Sources must only be handled by protective gloves or tweezers.

3. What to do in case of emergency

Any damages or suspected damages of radioactive sources must immediately be reported to the supervisor or the radiation protection officer. It is not allowed to continue work with such a source. Contaminated areas should be cordoned off immediately.

In case of fire, explosion or other catastrophic events besides the managing director and the janitor a radiation protection officer must be called in.

4. Radiation protection officers

Radiation protection officers for radioactive sources in the Institute for Nuclear Physics of the University of Cologne are:

Name	Heinze	Fransen	Dewald
Responsibility	Practical course	Experimental halls, work with radioactive sources, except of the practical course	Work in other institutes, Transport of radioactive sources, accelerator

References

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(!!! here you will find most of the information !!!)
- [4] MARMIER, P. und SHELDON, E.:
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- [5] RUTHERFORD, E.:
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