RUTHERFORD SCATTERING

Introduction

Alpha particles of uniform energy are scattered onto a gold foil. The dependence of the scattering rate $N$ on the scattering angle $\theta$ is measured and is compared with Rutherford's scattering formula.

Theory

In the Rutherford model of the structure of atom, all the positive charge of the atom and consequently essentially all its mass, are assumed to be concentrated in a small region in the centre called the nucleus. If the dimensions of the nucleus are small enough, an alpha particle passing very near it can be scattered by a strong Coulomb repulsion. The majority of alpha particles are scattered by a "scattering angle $\theta$" of less than 1°. A few particles have a substantially larger $\theta$, in the extreme case up to 180° (back scattering).

On the basis of this idea, Rutherford calculated the angular distribution $N(\theta)$ of the scattering rate. $N(\theta)$ is the number of $\alpha$ particles which is scattered in a time period of a determined interval $d\theta$ by an average angle of $\theta$. The result of the calculation is the "Rutherford's scattering formula". Except for proportionality factors, which are kept constant in this experiment, it provides us with the relationship for the angular dependence of the scattering rate:

$$N(\theta) \sim \sin^{-4}\left(\frac{\theta}{2}\right)$$

This proportionality is to be verified in this experiment.

In this experiment, the $\alpha$ particles emitted from a $^{241}$Am source pass through a slit of 1mm width onto a gold foil and leave this gold foil at various scattering angles. The scattered $\alpha$ particles are identified with a detector. By swinging the source in steps of 5°, the scattering rate can be determined for scattering angles between 5° and 60°.

Because of the very short range of $\alpha$ particles in air, this experiment must be carried out in vacuum.
Fig. 1 shows the geometrical arrangement of the components of the scattering chamber. Fig. 2 shows the geometry of the experiment. Note that the detector is firmly attached to the side wall of the chamber.

**Fig. 1** The scattering chamber

1. $^{241}\text{Am}$
2. Holder
3. Slit
4. Gold foil
5. Arm to swivel end

**Fig. 2** Scattering geometry with $^{241}\text{Am}$, collimator slit, gold foil and detector (D)
Set-up and procedure

**CAUTION**

- Never touch the gold foil.
- Do not directly touch the radioactive source - use the tweezers provided.

1. Vent the scattering chamber very carefully; otherwise the sensitive gold foil may be damaged.

   It is imperative for venting to proceed as follows:

   i) Close metal valve (on the outer wall of chamber).

   ii) Make sure that the vacuum pump is off and turn the glass stop-cock to the 'VENT' position.

   iii) Remove the gold foil from the danger zone of the in streaming air, i.e. align the foil so that it is parallel to the expected airflow.

   iv) Only then SLOWLY and CAREFULLY open the venting metal valve until a hissing sound is heard. Leave the valve in that position until the hissing stops and the chamber is completely vented.

2. Set up the experiment as shown in Fig. 3.

Fig. 3: Experiment setup for Rutherford scattering, electrical connection.
3. Turn on the potentiometer on the discriminator preamplifier all the way to the left \((U = 0)\).

4. Remove the lid of the scattering chamber. Set the digital counter dial to the ‘\(\sim\)’ position.

5. Preparing the scattering chamber (Fig. 1).

   Insert the \(^{241}\text{Am}\) source into the 4 mm socket of the swiveling holder. Place the 1 mm slit and the plastic sheet containing the gold foil on top of one another and insert both into the holder so that the slit points towards the source. Make sure the aperture slit of the detector (on the inner wall of the chamber) is perpendicular. Replace the lid of the chamber. Evacuate the chamber in the following way:
   
   i) The metal valve on the chamber should be in the 'open' position.
   
   ii) The glass stop-cock should be turned to the 'PUMP' position.
   
   iii) Switch on the vacuum pump.
   
   iv) Wait 5 minutes before you start counting. Leave the vacuum pump running.

6. For \(5^\circ \leq \theta \leq 30^\circ\), use 1mm slit.

   Set the detector at the angular positions \(\theta\) between \(5^\circ\) and \(30^\circ\) in steps of \(5^\circ\). For each setting, measure the time \(\Delta t\) taken to collect at least 20 counts \(N(\theta)\). Repeat for negative values of \(\theta\).

   For \(30^\circ < \theta < 60^\circ\), use 5mm slit.

   Replace the 1mm slit with the 5mm slit. Repeat the above procedure. Make sure you include \(\theta = 30^\circ\). Do not repeat for negative values of \(\theta\).

**Presentation of Results**

1. For \(-30^\circ \leq \theta \leq 30^\circ\)

   Tabulate \(\frac{N(\theta)}{\Delta t}\) in counts per minute as a function of \(\theta\) on a semi-log paper.

2. For \(5^\circ \leq \theta \leq 60^\circ\)
when \( \theta = 30^\circ \), an \( x \) times higher counting rate would be measured with the 5mm slit than with the 1 mm slit. The scattering rate for \( \theta > 30^\circ \) must then be divided by \( x \), in order to convert them to "1mm slit conditions".

Tabulate \( \frac{N(\theta)}{\Delta t} \) as a function of \( \theta \) and plot \( \frac{N(\theta)}{\Delta t} \) as a function of \( \theta \) on semi-log paper.

3. In order to compare the measured values with the theoretically predicted \( \sin^{-4}(\frac{\theta}{2}) \) dependence, plot

\[
f(\theta) = \sin^{-4}(\frac{\theta}{2})
\]

on a separate semi-log paper with the same division of the axes. The measured points and the theoretical curve can be made to coincide by displacement parallel to the ordinate. This parallel displacement corresponds to multiplication of the overall function with a corresponding proportionality constant.

4. Comment on your results.

Reference

Please scroll down to view Aluminium foil thickness and Rutherford Scattering Angle Graph.

Rutherford scattering chamber
Cylindrical vacuum chamber in which the scattering of particles at thin metal foils can be easily demonstrated both quantitatively and qualitatively. Also suitable for experiments on alpha spectroscopy.
With axial rotary transmission leadthrough for swirling the preparation and foil holder, and angle scale for a defined setting. Alpha detector is attached to the housing wall via a BNC plug. Additional rotary transmission leadthrough for a second foil in the particle stream. Chamber lid and base made from acrylic glass so that the scattering chamber is also suitable for projection using an overhead projector.

Angle scale (swivel range):
-150° via 0° to +150° with 5° divisions
Vacuum tube connection: 9 mm dia.
Measurement connection: BNC socket
Dimensions: 12 cm x 19 cm dia.
Weight: 1.8 kg

Scope of delivery
1. Vacuum chamber
2. Alpha detector with detachable slit screen 2 mm
3. Silt screen 1 mm
4. Silt screen 5 mm
5. Gold foil in holder (559 54)

Gold foil thickness
For experiments on Rutherford scattering.
Foil mounted on plastic screen.
Foil thickness: 2 μm
Diameter of the screen opening: 12 mm
Dimensions (frame): 50 mm x 50 mm

Graph

log N = f(θ) within a scattering angle of ±30°