Rutherford scattering: Measuring the angle dependence N (Θ) in Rutherford scattering

Alpha particles of uniform energy are scattered onto a gold foil. The dependence of the scattering rate N and the scattering angle Θ is measured and is compared with Rutherford scattering formula.

If alpha particles meet on a gold foil, they are deflected from their path ("scattering"). The majority of alpha particles are scattered by a "scattering angle Θ" of less than 1°. A few particles have a substantially larger Θ, in the extreme case up to 180° (back scattering). These initially qualitative observations can only be explained by assuming that the gold atoms have a very small nucleus, containing practically the whole atomic mass, and is positively charged.

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

$$N(\theta) \sim \sin^{-4}\left(\frac{\theta}{2}\right) \qquad (1)$$

This proportionality is verified in our experiment.

Because of the very low range of alpha particles in the air, this experiment must be carried out in a vacuum.

Fig. 1 shows the geometrical arrangement of the components of the scattering chamber, Fig. 2 shows the geometry of the experiment.

The alpha particles emitted from the Am-241 preparation fall through an aperture of 1 mm width onto the gold foil and leave this gold foil with various scattering angles. The scattered alpha particles are identified with a detector. By swinging the detector in steps of 5°, for example, the scattering rate can be determined for all scattering angles from 5° to 60°. With the setup we are going to use, the detector is not swung, but rather the preparation, slit and gold foil, which are attached on a common swivel arm.

The α detector is firmly attached to the side wall of the chamber.

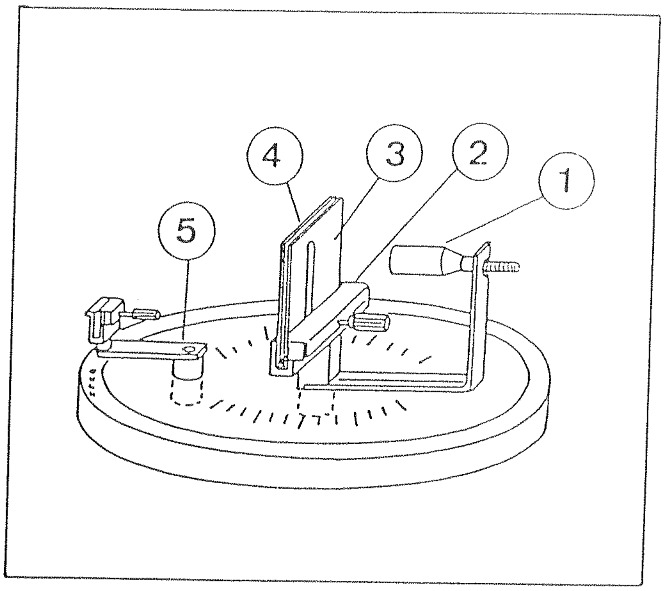


Fig. 1: The scattering chamber
(1) Preparation
(2) Holder
(3) Slit
(4) Gold foil
(5) Arm to swivel end

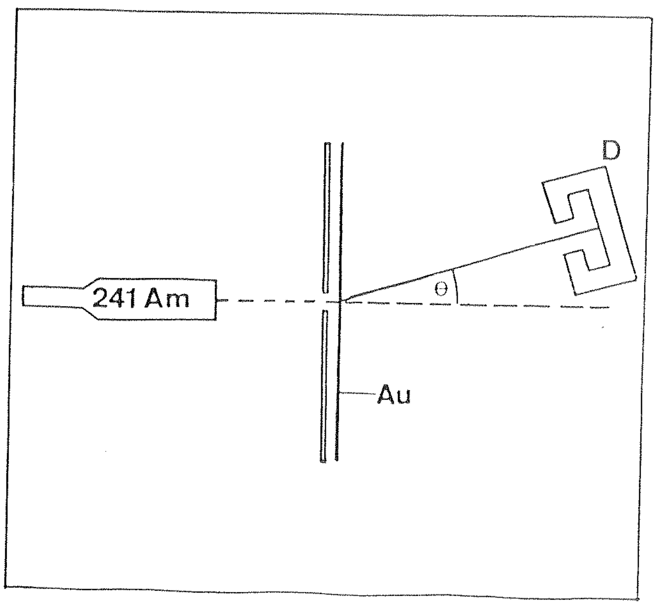
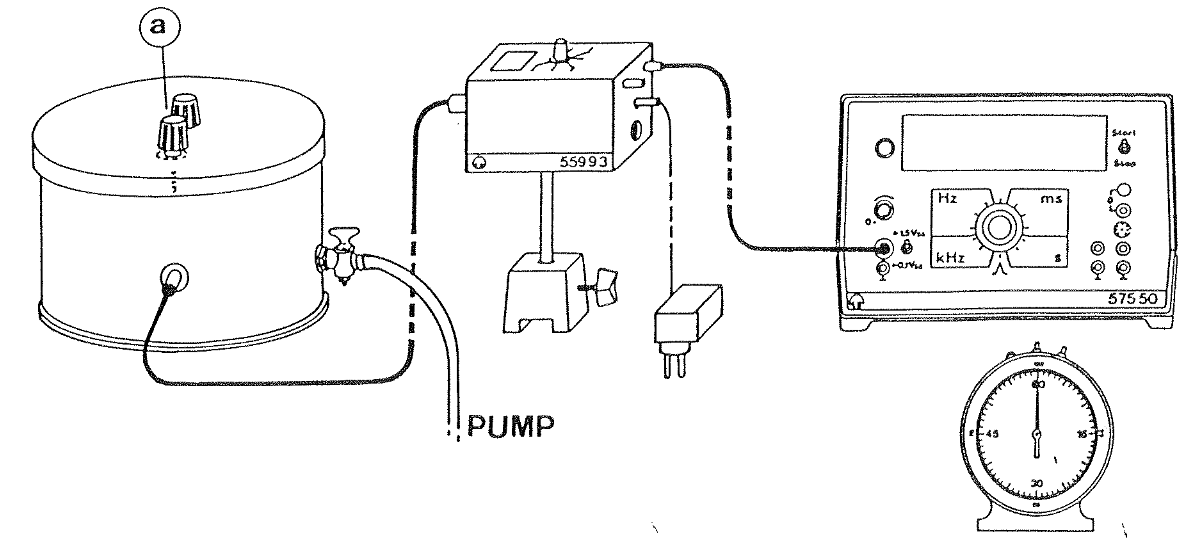


Fig. 2: Scattering geometry with preparation, collimator slit, gold foil and detector (D).



. ıg. 3: Experiment setup for Rutherford scattering, electrical connection

Apparatus:

1	Rutherford scattering chambers	559 56
1	Pump S 1.5, 220 V,50 Hz	101 01
1	Vacuum rubber hose 2 m	307 68
1	Digital counter	575 59
1	Discriminator preamplifier...........	559 93
1	Power supply unit, plug-in, 9.2 V	530 88
2	HF cables	501 02
1	Americum, AM-241 preparation, 333 kBq (9 µCi)	559 82
1	Saddle base	300 11
1	Stop clock	313 05

ting up:

⚠ Never touch the gold foil!

Air the scattering chamber very carefully (see operating instructions 559 56), otherwise you may destroy the sensitive gold foil.

Set up and connect the instruments as shown in Fig. 3. Turn the potentiometer on the discriminator preamplifier all the way to the left. Air the scattering chamber and take off the lid. Set the digital counter to "⩘".

Preparing the scattering chamber (Fig. 1):

Tnsert the preparation into the 4mm 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 them both into the holder so that the slit points towards the preparation. Swing the holder for swinging in (not needed during this measurement) to the top of the cover. Make sure the aperture slit of the detector (on the inner wall of the chamber) is perpendicular (with the mark at the top). Close the chamber and evacuate it.

Carrying out the experiment:

Note:
Protect the detector from light while measuring (especially from fluorescent light). If necessary, cover the chamber with a black cloth or similar.

Each time Θ = 5°, 10°, ... count at least 20 particles ($n(\Theta) \geq 20$). Note the measuring time Δt needed and calculate the counting rate $N(\Theta) = n(\Theta)/\Delta t$. When Θ is 30°, replace the 1 mm slit by a 5 mm slit and repeat the measurement for 30°, 40°, 50° and 60°.

Measurement example:

For the following series of measurements, 100 to 200 α-particles were counted per angle setting in order to keep the statistical error small.

Table 1

θ	n(θ)	Δt/min	N(θ)/min	
10°	170	5	34	1 mm slit
15°	136	15	9,07	
20°	140	33	4,24	
25°	103	40	2,58	
30°	101	105	0,962	
30°	124	16	7,75	5 mm slit
35°	170	40	4,24	
40°	190	80	2,38	
45°	133	93	1,43	
50°	96	100	0,96	
55°	84	120	0,70	
60°	78	200	0,39	

Θ : Scattering angle
$n(\Theta)$: Counting rate in the time Δt for the scattering angle Θ

$N(\theta) = \frac{n(\theta)}{\Delta t}$

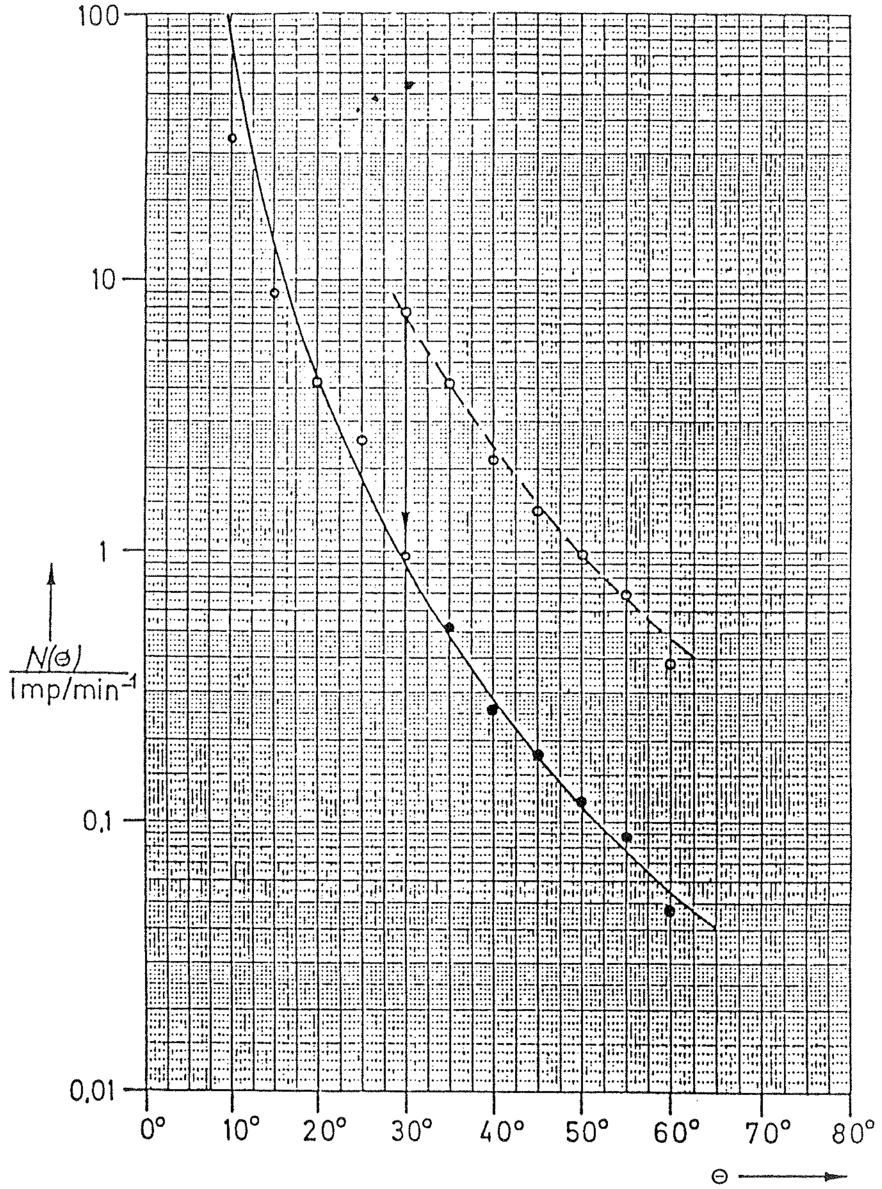


Fig. 4: N as a function of Θ
Open circles: Measured values
Closed circles: Measured values when $\theta > 30°$ converted to 1 mm slit
Conversion factor: The ratio of the counting rate at 30° with a 5 mm slit and a 1 mm slit
Solid line: Theoretical curve

Evaluation and results:

When $\Theta = 30°$, an eight times higher counting rate was measured with the 5 mm slit than with the 1 mm slit. The scattering rates for $\Theta > 30°$ must then be divided by 8, in order to convert them to "1 mm slit conditions".

The corrected measured values, and those for $\Theta < 30°$, are shown in Fig. 4 in floating point notation. In order to compare the measured values with the theoretically predicted $\sin^{-4}(\frac{\Theta}{2})$ - dependence of the scattering rate, the curve

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

is plotted on a second sheet of logarithmic paper with the same division of the axes.

The measured points and the theoretical curves must 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 (observe the logarithmic division of the axes). As can be concluded from Fig. 4, the measured points can easily be made to coincide with the theoretical curves.

Note:
If we remove the preparation from the scattering chamber and darken the chamber, the digital counter does not register anything, even after several hours.

False counts can occur when electrical devices (e.g. the pump) are turned on or off during a measurement and interfering impulses from the power source influence the digital counter.

Measurements of angles over 30° turn out especially well when the holder with the foil and the 5 mm slit is turned by 30° beyond the 90° alignment (Fig. 5). This prevents the α-particles from losing too much energy after the scattering process by having too long a path in the gold foil (Fig. 6).

If the 4 mm pin of the preparation is bent (the preparation turns in a circle when it is pushed in and then it turns around its longitudinal axis), a constant error of the angle can appear. In this case, it is necessary to displace the theoretical curve also parallel to the abscissa of the measuring diagram (Fig. 4), so that the curves $f(\Theta) = \sin^{-4}(\theta/2)$ and the measured points coincide.

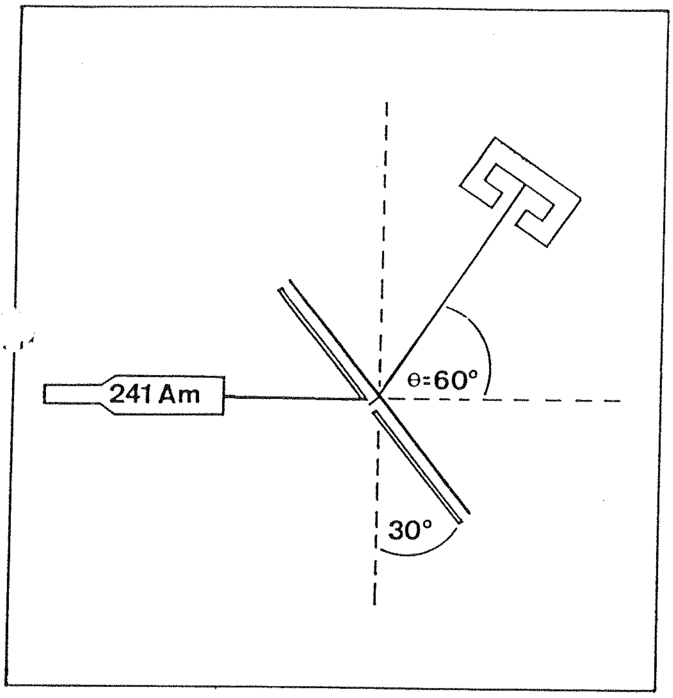


Fig. 5: Position of the preparation, slit, foil and detector during the measurement for large scattered angles. In the shown example: $\Theta = 60°$.

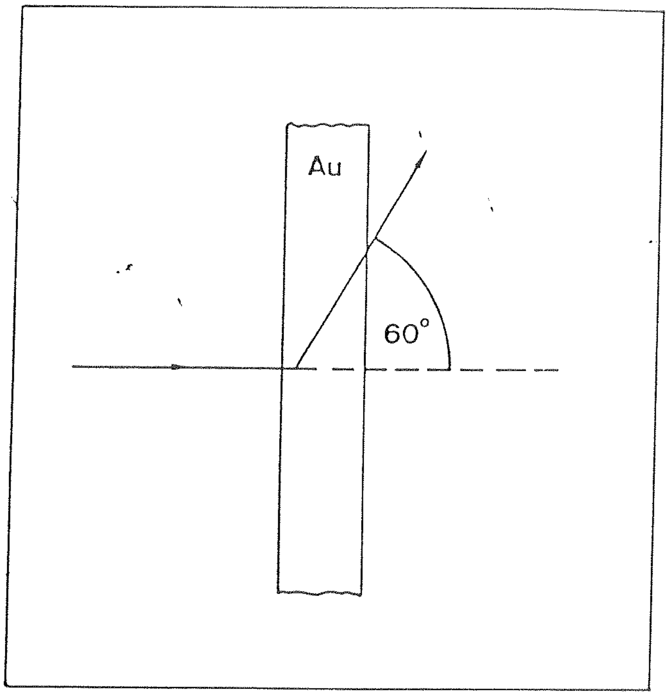


Fig. 6: The path of the α-particles in the gold foil with a scattering around 60° without the movement of slit and foil shown in Fig. 5