Rutherford scattering

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1 Abstract

The purpose of this experiment is to calculate the atomic number of aluminum by knowing the depth of two different sheets and the densities of both materials then measuring the count rates of each at different angles, finally by knowing the atomic number of one of the materials we can calculate the atomic number of the other, this resulted in a calculated value for the atomic number of aluminum of 42 particles within the nucleus of an atom.
Furthermore the experiment allows us to draw conclusions based on observations observed, these conclusions are directly responsible for the standard model of the atom and they took place as follows:

- The atom contains a dense nucleus which is positively charged
- The atom is mostly made of empty space
- Electrons are no present in the nucleus but are in fact somewhere else. (opposing the plumb pudding model)

2 Introduction

This first experiment that was targeting the structure of the atom was carried out by Ernest Rutherford in 1910-1911, the accepted structure of the atom was the plumb pudding however during the experiment Rutherford discovered that the structure of the atom could not have been accurately described by the plumb pudding model this is because during the experiment, alpha particles which are positively charged were being deflected by the electrostatic force, therefore the deflection could only occur if there is an isolated positive charge somewhere.
Furthermore this only states that there is a positive charge, another observation was made and that's the fact that only a very small fraction of the alpha particles fired at the gold sheet was deflected leading to the logical conclusion that the atom contained a very small (both in volume and charge) positively charged particle at the center of the atom and to equate for this positive charge the electrons which were previously predicted to be in the nucleus must be elsewhere around the atom, thus leading to the current (standard) model of the atom.

3 Procedure

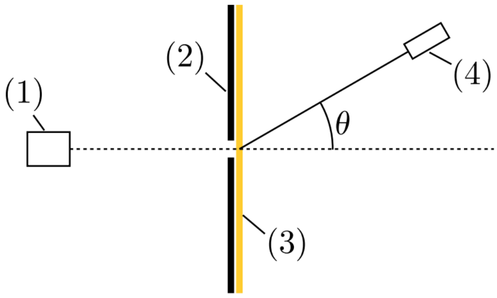
3.1 Equipment [1]

- scattering chamber
- vacuum pump
- discriminator preamplifier
- CASSY with timer box
- gold foil (2 um)
- aluminium foil (7 um)
- 1 mm slit
- 5 mm slit

3.2 Method

To preform this experiment a detector connected a cassy/computer was used to count the number of alpha particles over a period at a set angle, the detector (4) on figure 1/[F1] was placed inside of a vacuum chamber and it's static at all times, the gold leaf (3)[F1] was placed in front of a slit (2)[F1] which was either 1mm or 5mm the center of the slit was in parallel alignment with the radio active source (1)[F1], the gold/aluminum leaf along with the slit and the alpha particle source rotate with the axis of rotation being the center of the slit, this is how the angle of detection is changed, the alpha particles exit from (1)[F1] to through (2)[F1] and (3)[F1] and are detected by (4)[F1] at an angle θ, we allow the detector to measure the number of alpha particles detected at angles ranging from -30 to 30 in intervals of 5 degrees degrees over a recorded period thus allowing us to calculate the count rate at any given angle.

Figure 1: Showing the setup inside of the vacuum chamber [1]



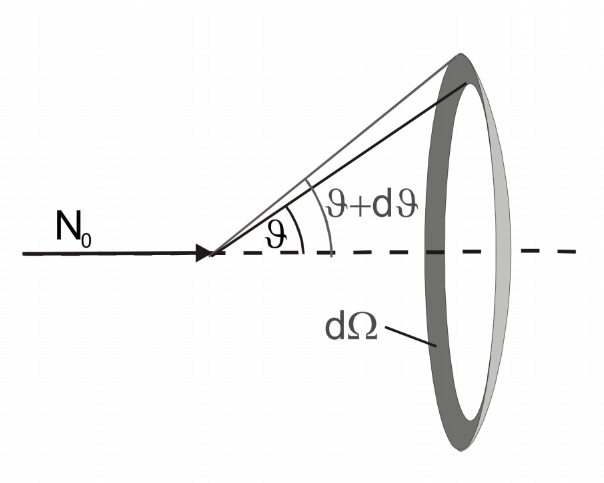
3.3 Objectives [1]

- 1) To record the direct count rate N_d of alpha-particles scatted by a gold foil as a function of the scatting angle θ.
- 2) To correct the count rates measured in one plane for the fact that the foil scatters in a 3D cone
- 3) To validate "Rutherford's scattering formula".
- 4) To determine the atomic number of aluminum experimentally.

For objective 1 :
We used the setup described and shown in section 1 and a gold leaf with a slit of 1mm to measure the count rate at all angles from -30 - 30 degrees at with a 5 degrees increment, while also measuring the gate time, all using the Cassy computer program.

For objective 2 :
To correct for the count rate, a correction factor will have to be calculated using figure 2, this factor will be multiplied by our measured count therefore producing a corrected count rate set of results.

Figure 2: The Correction factor [1]



For objective 3: To validate Rutherford's scattering formula, a plot of the experimental results and the theoretical curve which is produced by equation 1 will be plotted, if the theoretical curve can be adjusted by changing the constants A and B and if that curve fits the experimental data then that will validate the Rutherford scattering formula.

$$f(\theta) = \frac{A}{(\sin\left[\frac{\theta - B}{2}\right])^4} \tag{1}$$

For objective 4: To determine the atomic number of aluminum, equation 2, where the variables are defined as follows:

- N = Number of incident alpha particles
- c = atomic concentration of the foil
- d = foil thickness
- Z = atomic number of material

by knowing the properties of both materials used (gold and aluminum) apart from the atomic number of one of them and by measuring the number of incident particles for each at the same angle we can rearrange equation 2 to obtain an expression which is used to find the atomic number of that material foil.

$$\frac{N_{au}}{N_{ai}} = \frac{c_{au} d_{au} Z_{AU}^2}{c_{ai} d_{ai} Z_{Ai}^2} \tag{2}$$

4 Results

Figure 3: Showing the results for the count rate as a function of angle for the gold leaf

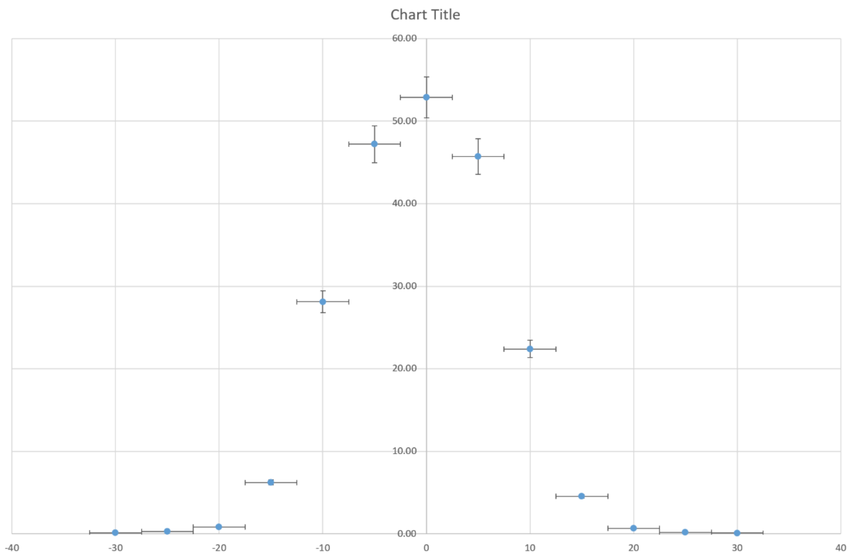


Figure 4: Showing gold leaf experimental results agains the theoretical curve from equation 1

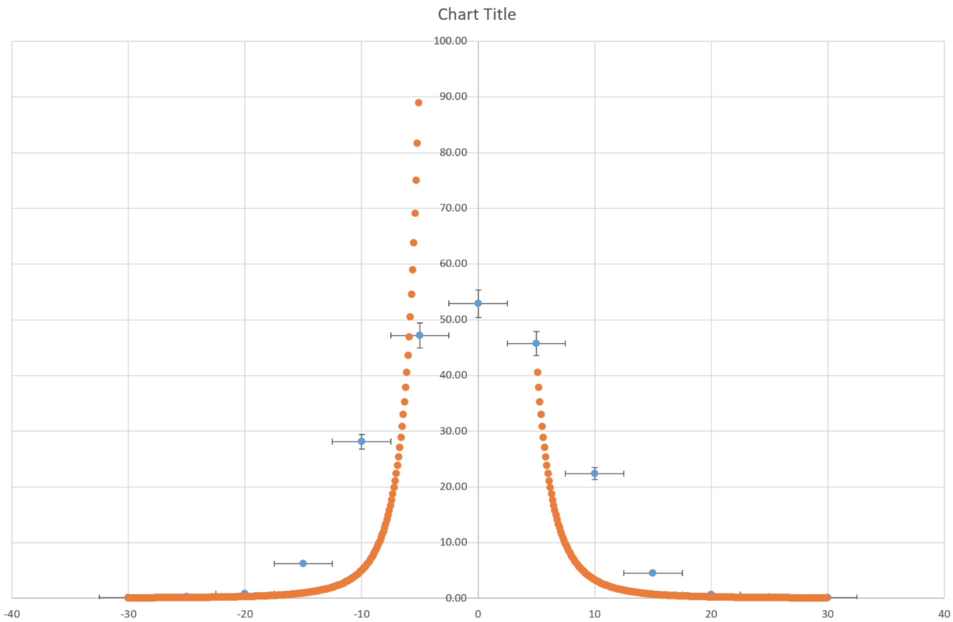


Figure 5: Showing the experimental and theoretical curves on a logarithmic scale

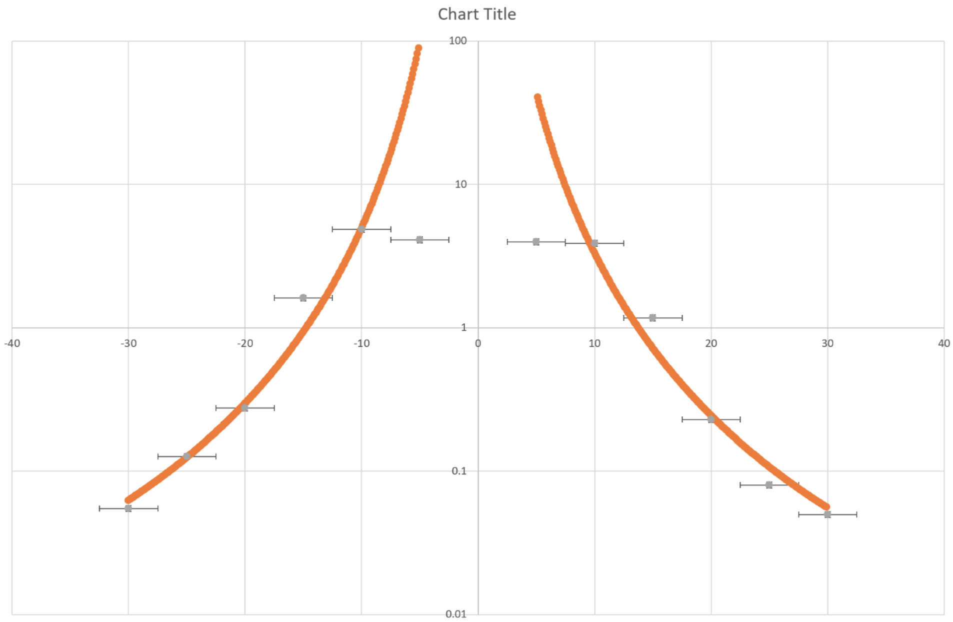


Table 1: Showing the results for comparing aluminum and gold

angle	Material	count	count error	gate time	count rate	count rate error	Aluminium Reproducibility	
-15	Aluminium	7830	368	60	130.50	6.1335	9550	
-15	Gold	7383	347	60	123.05	5.78335	9657	
5	Aluminium	7089	333	60	118.15	5.55305	9652	
5	Gold	8569	403	60	142.82	6.71254	9727	
25	Aluminium	6695	315	60	111.58	5.24426	9540	
25	Gold	8173	384	60	136.22	6.40234	9625.2	mean
							79.06769252	sdev
							0.82%	%

5 Discussion

Analyzing the results, from figure 3 which is a graph showing the count from the gold leaf as a function of the angle in degrees, where the 1mm slit was used.It shows that as the angle approaches 0 degrees the count starts to increase exponentially this is due to the fact that the nucleus of the atom is very small thus many alpha particles don't interact with it therefore the very high count at 0 degrees and the difference between the 0 degrees point and all other deflection angles is due to the electrostatic force being a function proportional to the distance squared therefore as alpha particles interact with the nucleus via the Electro-static force and repel, there would be a great difference in the angle of deflection for a small change in the distance of interaction between two different alpha particles and a nucleus, this would explain the behaviour shown by figure 3.
Furthermore figure 4 shows a fit of the experimental data compared with the curve generated by equation 1 with A = 0.00023 and B = -0.00873, the fit is further evaluated using a logarithmic scale therefore producing figure 5, which shows that the experimental data suitable fits the theoretical plot produced by Rutherford's equation, this confirms that Rutherford's theory is correct because a real measurement resulted in a good estimation, therefore it's correct to state that Rutherford's equation accurately describes the reality of how particles interact in the context of the gold leaf experiment.

On the other hand table 1 shows measurements taken for both aluminum and gold for 3 different angles where the count, gate time and therefore the count rate was calculated. This allows us to calculate the atomic number of aluminum using equation 2, where the only unknowns were the count rates for both which are now obtained from table 1 and the atomic number of Aluminum (Z_{ai} is known to be 72), when re-arranging equation 2 for Z_{au} and solving the equation for all three different result sets obtained by the angles in table 1 estimated values for the atomic number of aluminum were:

- (38.13 at 15 degrees)
- (47.8 at 5 degrees)
- (40.6 at 100 degrees)
- average = 42 particles

These Results obtained are too far away from the real value of the atomic number of aluminum $Z_{au} = 13$ therefore an error of 307.6%, this error originated from an incorrect count from the aluminum or gold leaf on table 1 for ALL angles, this is further discussed in section 6.

6 Error analysis

In this experiment many variables could have been sources of error and to minimize this effect some precautions were taken to ensure that the results obtained were accurate.
To start, due to the nature of this experiment or the fact that alpha particles are fired and are expected to only interact with the the atoms in the leaf, we had to ensure that the environment in which the experiment took place was completely vacuumed and sealed, however this is an uncontrollable variable as we cannot determine if we have achieved a complete state of vacuum inside the chamber, this may effect the count rate by either increasing it or decreasing it as the alpha particles are able to interact with the air particles as well as the leaf material, this may result in a deflection towards the detector or away from the detects however given that most alpha particles are projected to never hit the detector the presence of air molecules which could be described as 'mirrors' would result in much more frequent deflections towards the detector than away from it therefore in an unsealed chamber the count rate is expected to increase by a lot more, this may have been the reason for the inaccuracy in the calculation of the atomic number of aluminum obtained in section 4 which depends on the count rate obtained from measurements.

On the other hand smaller sources of error include, background radiation and radiation from the violet light from the ceiling light which was reduced by placing a cover over the vacuum chamber. Furthermore the set up of the discriminator may have inaccurately set therefore a regular check every session was made to ensure that the noise detected by the discriminator was only caused by the alpha particles making contact with the detector.

7 Conclusion

To conclude this experiment aimed to show how the current standard model of the atom was discovered by a series of observations and conclusions made from them, that may correctly model how the real atom structure may be. On the other hand the experiment further illustrates it's capabilities of allowing us to model and predict the mechanics of the atom and shows that they're measurable by allowing us to calculate the atomic number of any material sheet by simply measuring the count rate then comparing with the count rate of a material sheet for which the atomic number is already known.

Overall this experiment opened the door for particle physics allowing us to further investigate the atom and smaller particles, to make further discoveries using this knowledge and also allowed us to discover the quantum world in which something is nothing, nothing is something and everything we know is just stable scaled up version of what truly lies beneath.

References

[1] UKC SPS. "Rutherford scattering labscript 5". In: (2018). URL: file:///Users/M/Downloads/Rutherford_Scattering_Sept%5C%202018.pdf.