Rutherford Scattering Experiment Lab Report (Group VII)

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Abstract

Through an experiment originally designed by Rutherford, we experimentally verified the theory of scattering of alpha particles off gold foils. More specifically, the experimental result demonstrated that the probability of scattering, or *cross section* denoted by $P(\theta)$, is proportional to $1/\sin^4(\theta/2)$ and thickness of the scattering foils.

1 Introduction

Prior to well-known Rutherford's experiment, scientists at the time modelled [1] the structure of an atom using what is known as a "Plum Pudding" model (shown in Fig 1).

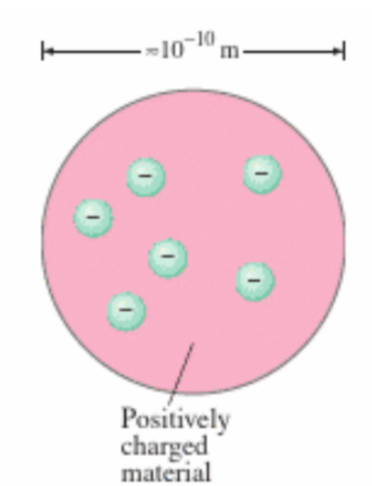


Figure 1: The Plum Pudding Model [1]

In which, the atom is described as a mostly charged sphere with negative charges distributed across the sphere. To test this, Rutherford designed an experiment where a beam of alpha particle are shot towards a gold foil. By the Coulomb Force, the expectation is that they would "bounce" off another, much like the macroscopic picture of elastic balls bouncing off. The theory and derivation is discussed in following section.

1.1 Theory

A schematic diagram is given below with regard to the scattering of alpha particles: From Newton's 2nd Law and equating force to be the Coulomb force, the magnitude of momentum is given to be:

$$\Delta p = \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0} \int \frac{1}{r^2} \cos\phi \, dt$$

where Z_1, Z_2, e are the charge of the alpha particle, charge of the gold foil respectively.

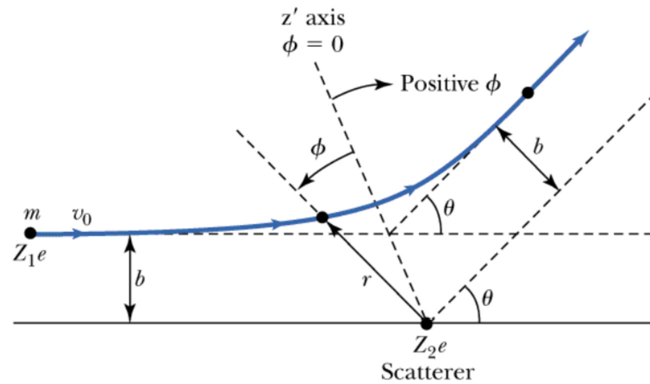


Figure 2: Schematic Diagram

Corollary By considering the conservation of momentum, we obtain the following expression of dt/dr:

$$\frac{dt}{dr} = \frac{d\phi}{v_0 b} \tag{1}$$

and by sine rule,

$$\Delta p = 2p\sin(\theta/2) \tag{2}$$

Expression of the probability of scattering known as the *"cross section"* is stated here without proof [2]:

$$P(\theta) = \left(\frac{Z_1 Z_2 e^2}{4\pi\epsilon_0}\frac{1}{4K}\right)^2 \frac{1}{\sin^4(\theta/2)} \tag{3}$$

where K is the initial kinetic energy

Since the initial KE, charges of the particles are constant, we arrive at the relationship below:

$$P(\theta) \propto \frac{1}{\sin^4(\theta/2)} \tag{4}$$

Furthermore we make the hypothesis that:

$$P(\theta) \propto \text{Thickness of Foils} \tag{5}$$

1.2 Aim of the Experiment

The aim of our experiment is, therefore, to experimentally verify our relations from equation (4) and (5). The fundamental principle we are working with here is that count rate measured by a count meter is proportional to the probability of scattering $P(\theta)$. From this, we want to measure the count rate and plot against $1/\sin^4(\theta/2)$ and thickness to verify the aforementioned quantities.

2 Health and Safety

This apparatus contains a sealed radioactive source and is under vacuum. We will use implosion guards at all times in order to make sure we are protected if something goes wrong with the chamber. Magnates are also used for this experiment which can cause damage to electrical devices such as phones and computers, also mechanical devices such as watches. In order to protect both ours and the labs property we should ensure that we remove all devices from our person and clear the surrounding area as to prevent accidents. The magnets are also heavy and needed to be handled with care.

3 Experiment

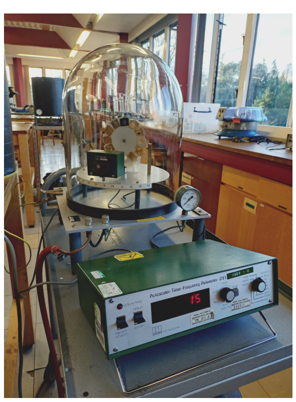
3.1 Experimental Set Up

For this experiment we will make use of an ESI Rutherford scattering apparatus which consists of a rotatory vacuum sealing the apparatus. The beam is emitted by a collimator and to control the intensity of alpha particles being emitted, 6 attenuator foils of which one is blank were used which vary in thickness; 10 scattering foils of which two are blank and two are made of a different metals (i.e. Silver and Aluminium) are used for this set up. The alpha particles are being detected by a ratemeter. Lastly, the measurement for the radiation intensity of the scattered alpha particles colliding with the detector will be done with the use of an ESI scaler/ratemeter and manual.

(a) Implosion Guard

(b) Scatter and Attenuator Foils

(c) Top Down View



(d) Front View

Figure 3: Experimental Setup

3.2 Experimental Procedure

3.2.1 Experiment 1

For our first experiment, we will test and verify the relationship shown in equation (4). For the count rate at different angles θ we kept the attenuator and scatterer foils constant. We took 10 readings by varying the angle of detection for the incoming alpha particles for an interval of $1 \leq \theta \leq 10$. However, only the first 5 angles have been taken into account as they follow the theoretical model as shown in figure (4).

3.2.2 Experiment 2

In this experiment, we change the thickness and material of the choice of scattering foil, to see how the alpha particles deflect off the different foils. To find our errors, we needed to take an array of measurements (3 in our case) and then we computed a mean and the standard deviation which were done in Excel by Conrad.

A common issue that occurs is knocking the casing when taking off the implosion guard, this can shuffle the angle creating an incorrect measurement. It is important to make sure not to touch the casing when changing the foils! We also kept our attenuator foil as constant, namely, Foil No. 3. After collecting and tabulating all of our measurements, we then proceeded to plotting our data which can be seen in Figure 5.

4 Results

From our data (see Appendix A), we plotted the following results which have been linearised to better show the relationship between the theoretical variables. Figure 4 and 5 demonstrate "Count Rate against $1/\sin^4(\theta/2)$" and "Count Rate against Scattering Foil Thickness". From which we could observe the linear relationships between the variables plotted, which implies our results do, indeed, follow from and verify the theoretical model.

For experiment 1, something that had been observed is that despite using a blank slot (i.e. without attenuator and scattering foil) we still had scattering of alpha particles occurring. The possible explanation behind this is that there is some form of natural scattering occurring. This should be taken in mind whilst interpreting the plots and for further work, for example, where we choose to carry out experiment 1 but instead with a certain choice of foil.

NB: It is important to note that, for the plot in Figure 3, we only plotted for $\theta \in [1, 5]$ as they fit the theoretical model.

5 Conclusion

Through our two experiments in which we varied the angle; the thickness of the foils, respectively, we experimentally showed that:

- $P(\theta) \propto$ Count Rate $\propto 1/\sin^4(\theta/2)$
- $P(\theta) \propto$ Count Rate $\propto$ Thickness

which agrees with the theory with reasonable uncertainties as discussed in the Results section.

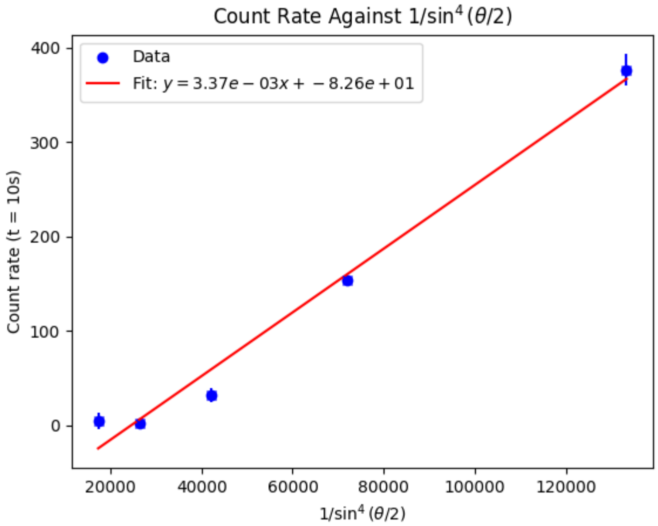


Figure 4: Count Rate against $1/\sin^4(\theta/2)$

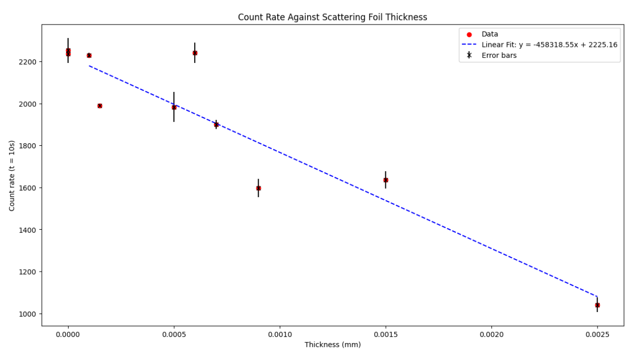


Figure 5: Count Rate against Thickness of Varying Foils

References

[1] Giancoli DC. Physics for scientists & engineers with modern physics. London: Pearson Education Limited; 2016.

[2] Simon Fraser University. 'Introduction to Nuclear Science' (NUCS 342) Notes for Lecture No. 22, https://web-docs.gsi.de/~wolle/TELEKOLLEG/KERN/LECTURE/Fraser/L22.pdf; 2011. [Online; accessed 04/03/2025].

A Raw Data

θ	N1	N2	N3	SD	Mean	$1/\sin^4(\theta/2)$
1	1083	1069	1074	7.1	1075	172437835
2	1036	1056	1072	18.0	1055	10779006
3	929	950	926	13.1	935	2129727
4	834	832	841	4.7	836	674098
5	815	814	841	15.3	823	276237
6	370	363	395	16.8	376	133291
7	155	153	153	1.2	154	71994
8	40	30	25	7.6	32	42234
9	1	1	3	1.2	2	26389
10	0	1	15	8.4	5	17331

Table 1: Experiment 1 Raw Data

S. Foil No.	Thickness	Density (kg/m^3)	N1	N2	N3	Mean	SD
1	0.0001	19281	2235	2217	2237	2230	11.0
2	0.00015	19281	1997	1984	1990	1990	6.5
3	0	0	2247	2315	2197	2253	59.2
4	0.0005	19281	1924	1963	2062	1983	71.1
5	0.0007	19281	1913	1874	1910	1899	21.7
6	0.0009	19281	1561	1583	1645	1596	43.6
7	0.0025	19281	1073	1047	1003	1041	35.4
8	0.0006	2698	2263	2187	2277	2242	48.4
9	0.0015	10500	1599	1680	1627	1635	41.1
10	0	0	2262	2219	2229	2237	22.5

Table 2: Experiment 2 Raw Data