Rutherford Scattering

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1 Abstract

In this experiment α-particles from an Americium-241 source were fired at a thin sheet of gold foil at varying angles to investigate the structural properties of the atom, as per Rutherford's famous 1909 Gold Foil Experiment.

2 Introduction & Theory

At the start of the 20th century, the most popular model for the atom's structure was the so-called *Plum-Pudding* model developer by J.J.Tompson. This proposed that the atom was a ball of positive charge (the pudding) within which the negative electrons were embedded (the plumbs). Rutherford expected the α-particles fired at the atoms of gold to be only slightly deflected. What in fact happened was that most passed straight through, and only a few were deflected at wide angles. This was such a shock to Rutherford that he famously said
" *It was almost as if you fired a fifteen-inch shell at a piece of tissue paper and it bounced back and hit you* ". It was from these observations that he formulated his orbital atomic model.

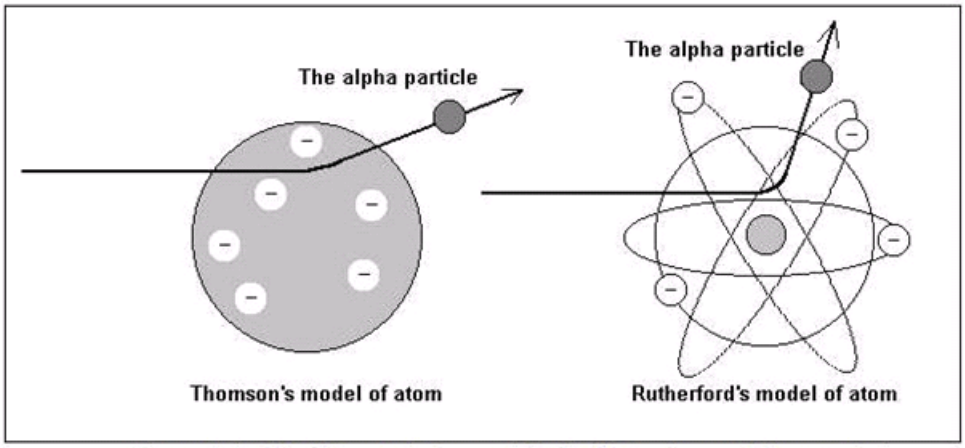


Figure 1: J.J. Thompson's Plum-Pudding model vs. Rutherford's Nucleus Model

Further to this, Rutherford calculated the hyperbolic trajectories of the scattered particles. He derived an expression relating the the Count Rate, R of the particles to the scattering angle, θ and found the following direct proportionality

$$R \propto N \left(\frac{Zz}{E}\right) \text{cosec}^4 \left(\frac{\theta}{2}\right)$$

where z is the atomic number of the alpha particles, Z that of the scattering foil, E the kinetic energy of the particles, and N the number of scattering centers in the foil.

3 Experimental Method

The apparatus was set us as in the diagram. The swivel arm was set to the 0^o position. The pump was then turned on to remove all the air from the chamber. The time for at least 10 particles was recorded for a range of values of θ from 0^o to 30^o.

The slit in front of the gold foil was then changed from a 1mm slit to a 5mm slit to allow more particles through. The time for at least 10 particles was then re-recorded for 30^o to calculate the conversion factor. Following from this the time for a count of at least 10 particles was recorded for a range of angles from 45^o to 60^o as above.

The count rate R was calculated and a graph of R against θ was plotted.

We then plotted a graph of

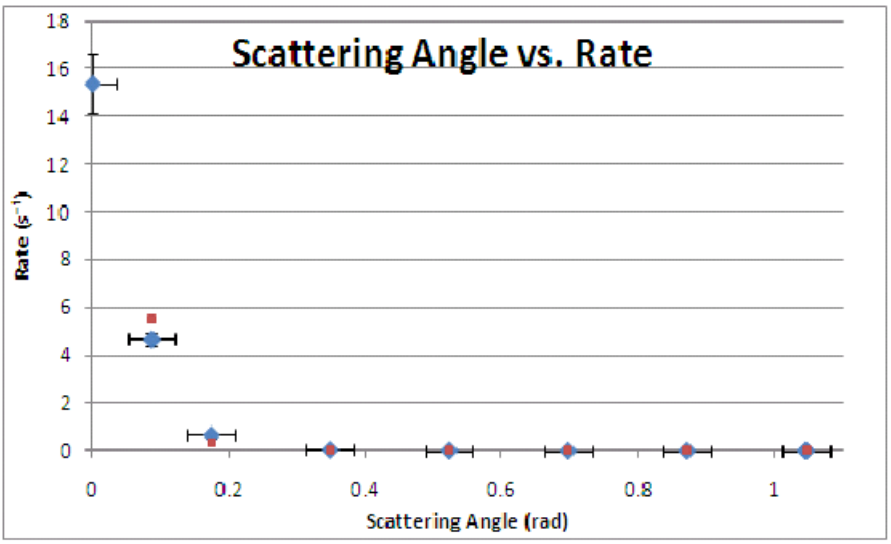
$$R \text{ against } \log_{10}\left(\text{cosec}^4\left(\frac{\theta}{2}\right)\right)$$

4 Results & Analysis

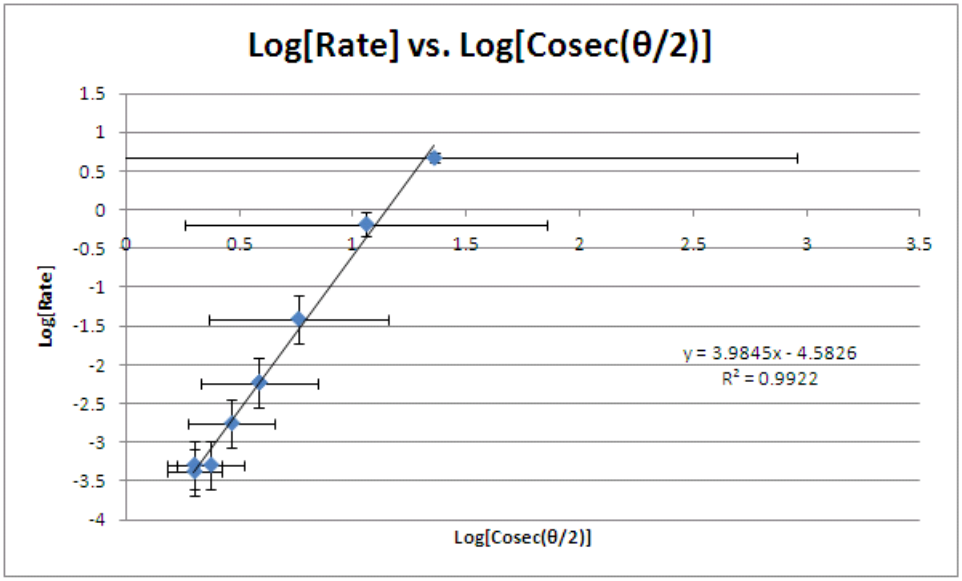
Scattering Angle $\theta \pm \Delta\theta(^o)$	Count $N \pm \Delta N$	Time $t \pm \Delta t(s)$	Count Rate $R \pm \Delta R(s^{-1})$
0 ± 0.035	154 ± 1.250	10 ± 0.1	15.4
5 ± 0.035	280 ± 0.279	60 ± 0.1	4.6667
10 ± 0.035	39 ± 0.104	60 ± 0.1	0.65
20 ± 0.035	10 ± 0.0122	258 ± 0.3	0.0388
30 ± 0.035	10 ± 0.0018	1712 ± 0.3	0.0058
30 ± 0.035	10 ± 0.0018	175 ± 0.3	0.0058
40 ± 0.035	10 ± 0.0005	589 ± 0.3	0.0017
50 ± 0.035	10 ± 0.0002	2039 ± 0.3	0.0005
60 ± 0.035	10 ± 0.0002	2031 ± 0.3	0.0005
60 ± 0.035	11 ± 0.0001	2727 ± 0.3	0.0004

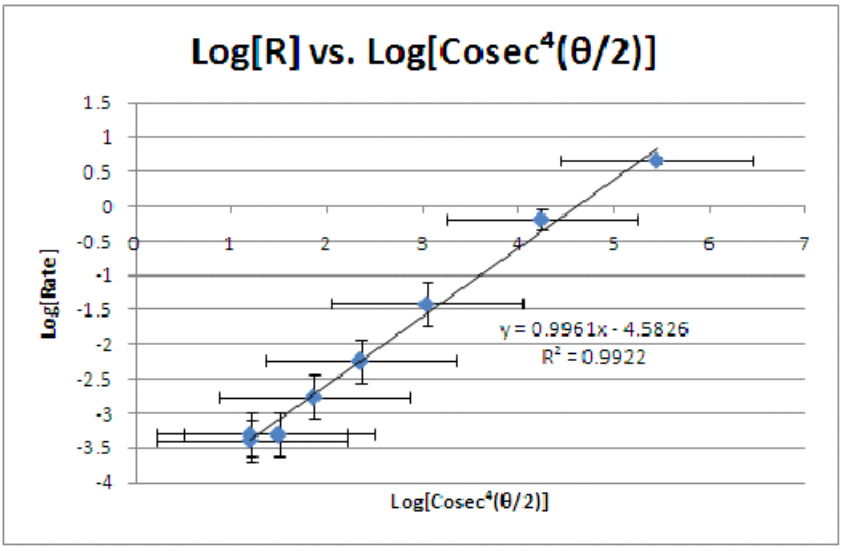
In the above the conversion factor for the wider slit is taken into account.

A graph of the Count Rate vs. the Scattering angle,



and that of the $\log(R)$ vs. $\log\left(\text{cosec}\left(\frac{\theta}{2}\right)\right)$ and vs. $\log\left(\text{cosec}^4\left(\frac{\theta}{2}\right)\right)$ respectively.





For the initial graph, we can estimate the slope $m \approx 1$, while for the second $m \approx 4$. This validates Rutherford's proportionality relationship

5 Error Analysis

The error of the various measurements taken during the experiment were calculated as follows.

$$\Delta\text{Count} = \sqrt{\text{N}}$$

$$\Delta\text{Count Rate} = R \times \sqrt{\left(\frac{\Delta N}{N}\right)^2 + \left(\frac{\Delta t}{t}\right)^2}$$

$$\Delta \log\left(\text{cosec}^4\left(\frac{\theta}{2}\right)\right) = \frac{4\Delta\theta}{\tan\left(\frac{\theta}{2}\right)}$$

where N is the Count and R the Count Rate.

The error in the time was taken to be ± 0.1s when using the timer, and ± 0.3s when using the stopwatch.

6 Conclusions

Rutherford's atomic model was validated by repeating Rutherford's experiment with a slightly different apparatus. α-particles were found to be less frequent when the detector angle was increased. But particles scattered at angles too great to fit with the plum pudding model were found, and the relationship between the count rate and the scattering angle was shown to be correct through graphical methods. This leads us to the conclusion that atoms consist of a centralised positive mass and orbiting electrons.