Physics 4321 Lab Report IV

Rutherford Scattering Experiment

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Abstract

In this lab, we would examine the scattering of α-particles off of gold foil mimicking the Rutherford experiment. We measured the number of α-particles that were deflected through an angle θ into the detector and plotted log N[(θ)] against log[sin(θ-θ_0)] for the gold foil. The fitted line, which was a negative linear line, showed that the data taken was consistent with the Rutherford Scattering Formula. We also calculated the atomic number of Aluminum to be 10.4 ± 3.6 using the scattering rates for the gold and aluminum foils for 10 degrees.

Introduction

The structure of the atom has been a question of the human beings for a long time. In the late 19th century, based on Newtonian mechanics and Maxwell's electromagnetic theory, J.J. Thomson proposed a "plum pudding model" which claimed that the atom is composed of electrons surrounded by a group of positive charge like the negative "plums" surrounded by positive "pudding". Thomson discovered that the atom was made of both positive and negative charges but was not clear about how exactly the charges located in the atom. The "plum pudding model" also did not have any explanation for the quantized nature of the hydrogen spectrum, as indicated by the Balmer formula and the Ritz combination principle for atomic spectra. [1]

Then at 1897, Rutherford and his collaborators Geiger and Marsden decided to fire helium ions at thin metal foils. Since the helium ions, or α-particles, were very small. The diffraction of the helium ions at different angles could give a picture of the structure of the atom. If the atom structure were like the model of plum pudding, then the fraction of particles scattered through an angle of θ would fall off like a Gaussian since the α-particles would just pass straight through the foil. However, the statement only seemed accurate for small angle scattering, and not so much for large angles scattering. [2]

The only possible explanation for this large angle deflection was to assume that the total mass of the atom was highly concentrated in the center on the foil. This way, the high concentration of charge would produce the necessary Coulomb force for the large angle scattering to occur. [3] The Rutherford scattering experiment provided lots of views into the atoms and made a revolution in the model for the atomic structure. In this experiment, we redid the Rutherford scattering using gold foil and found that the fitted line for the data appeared to be linear and corresponded to Rutherford Scattering Formula. We also found that the atomic number for aluminum to be 10.4 ± 3.6, which was within the range of the experimental data of 13. [4]

Theory

The scattering geometry of the α-particles was as follows in Figure 1.

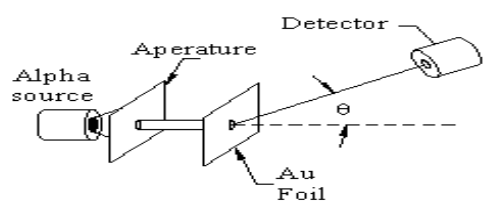

Figure 1. Scattering Geometry for α-particles in the Rutherford Scattering

According to Rutherford's assumption of the point charges and a pure coulomb repulsion, the number of particles number of α particles, N(θ), that are deflected into an angle θ after passing through the foil according to the following equation:

$$N(\theta)=K\frac{1}{\sin^4(\frac{\theta}{2})} \qquad \text{Eq(1)}$$

With K= $(1/4\pi\varepsilon_0)^2$ $(zZe^2/2Mv^2)^2$, where ε_0 = 8.85 x 10^{-12} F/m, z = number of protons in alpha particles, and Z = number of protons in the atoms making up the foil (that is, the atomic number of the foil element), M = mass of the alpha particles, and v = the velocity of the alpha particles.

If we take the log of both sides, we got the transformed form of the Rutherford Scattering:

$$\mathrm{Log}(N(\theta))=-4K^{*}\mathrm{Log}(\sin(\theta/2)) \quad \text{Eq(2)}$$

We used the α-particles to hit the gold foil with the experimental set up as follows in Figure 2.

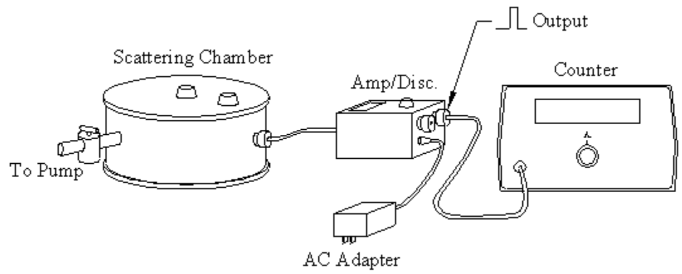

Figure 2. Experiment setup and electrical connections for Rutherford Scattering that includes a scattering chamber with shut off value, pump(not shown), discriminator/preamplifier, AC adapter, and counter

For small degrees, we counted using the 1mm thin slit. For larger angles, we used the 5mm wider slit since the larger angles were harder to get count. We then converse the rates between the two slits based on the counting rates that we took for 30 degrees angle for both slits using the conversion equation below.

$$k = \frac{N(30°)\,with\ 5mm\ slit}{N(30°)\,with\ 1mm\ slit} \quad \text{Eq(3)}$$

To scale the measured values bigger than 30°, divide the counting rates determined for θ=40°,50°,etc. by the conversion factor k.

During the experiment, our equipment broke down once since we adjusted the counter parameter mistakenly so that we needed to set up everything all over again. Thus, we conversed the count rates for the newly measured data as well.

Data

The Plot of log[N(θ)] against log[sin(θ-θ_0)] is as follows, with N(θ) representing the count rates and θ_0 representing the zero degree value for the measurements:

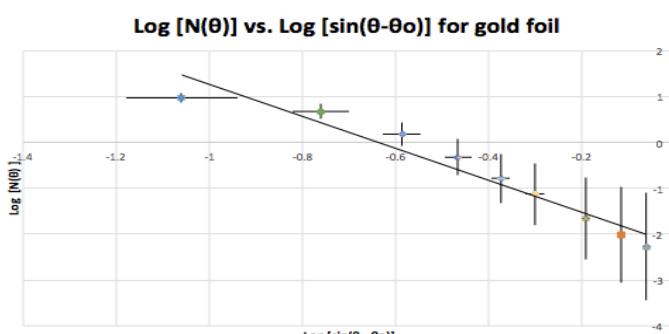

Figure 3. The plot of the data taken for log[N(θ)] against log[sin(θ-θ_0)] to determine if the line fit the Rutherford scattering equation

The slope of the line was consistent with the transformation form of the Rutherford Scattering in Eq(2), which showed a negative linear trend.

Conclusion

Taking a look at our fitted plot in Figure 3, we noticed that the error bars appeared to be bigger at x-axis for smaller angles and the error bars appeared to be bigger at y-axis for larger angles. The reason for this was that the standard error for angles was the same for all the angles, which was 1.5°. As the standard error was the same for all angles, the smaller angles would have a bigger impact on their log[sin(θ-θ_0)] values. As for the bigger angles, there was a bigger uncertainty in the count rate since the count rate was really small. Thus, the error bar would become bigger for the larger angles. The slope of the line was -3.5±1.2. Thus, the slope of our data was consistent with the Rutherford Scattering equation in Eq(2) that had the slope of -4.

Next, we calculated the atomic number of aluminum comparing the scattering rates of the gold and aluminum foils for a scattering angle of 10 degrees. Then we used the Rutherford Scattering equation to determine the relationship between the atomic number of Au and Ag using the following equation:

$$\frac{N_{Au}=Z_{Au}^2 d_{Au}}{N_{Al}=Z_{Al}^2 d_{Al}} \qquad \text{Eq(4)}$$

where d=thickness of foil, Z= atomic number, and N=counting rate.

And we found that the atomic number for Aluminum to be 10.4 ± 3.6 which was within the range of the documented value 13.

In general, our trend and calculated atomic number for Aluminum corresponded to the Rutherford Scattering Equation in Eq(1) and Eq(2). Other possible random error included that we changed the setting in the middle of the experiment and rate conversion might not be as accurate. Other possible systematic error might be that the air inside was not completely pumped out so that there were still air molecules inside to disturb the measurements. Other than that, the smooth trend on the data shows that there was no big systematic error such as broken of the gold foil.

The Rutherford Scattering Experiment was a great success in helping us to determine the structure of the atom. It could be further used to determine the foil thickness or to discover other scattering characteristics such as “elastic scattering” and “inelastic scattering”. What’s more, the Rutherford scattering technique may also be used to study the surface region of crystals to determine the crystalline structure and surface impurities and so on. [5]

Reference

[1] H. Gon., G. Bernard. “J. J. Thomson's plum-pudding atomic model: The making of a scientific myth”*. wiley.com*
[2] A. Melissinos, Experiments in Modern Physics: Rutherford Scattering (Academic Press, 1966), chap. 6, pp. 226– 252.
[3] J. L. Staff, Junior lab reader (1990).
[4] “Elements-Al”. *rsc.org.*
[5] D.V. Morgan. “On the application of Rutherford scattering and channeling techniques to study semiconductor surfaces”. *sciencedirect.com*