Study of Rutherford Scattering

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Rutherford Scattering was performed to investigate structure of atom, where a beam of α particles are incident on metal and observed that they are scattered at different angles. Most of the particles pass through the metal, some scatter and very few rebound. In experiment replicates the same experiment with smaller time intervals and also calculate the atomic number of Aluminium. We found nuclear charge of aluminium as 23 with relative error of 76.92%.

Keywords: Form factor, Scattering

I. THEORY

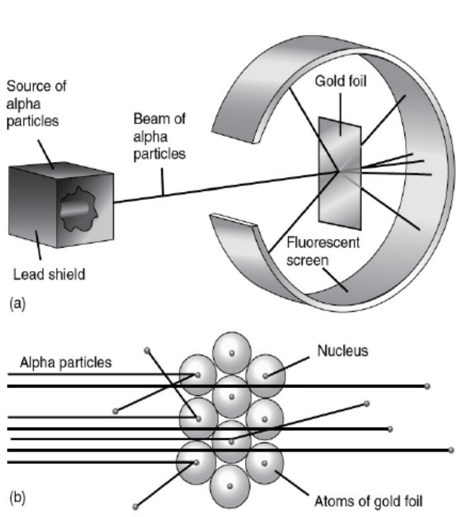

Figure 1: Rutherford Scattering experiment

Geiger and Marsden under Rutherford performed experiment where collimated α particles were collided with a gold foil and the scintillation were seen on the florescent screen. It was observed that most particles passed through the foil, few scattered at very small angles, and very rarely some back scattered, implying that the most part of the atom is empty, hence nucleus was discovered.

Rutherford calculated the angular distribution of scattering rate N(θ), which is defined to be no. of particles scattered during time unit determined interval dθ around average angle θ.

$$N(\theta) = N_o.C_f.d_f.\frac{Z^2.e^4}{(8\pi\epsilon_o.E_\alpha)^2 sin^4(\theta/2)} \tag{1}$$

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N_o is particle rate, c_f is atomic concentration, d is thickness of foil, Z is charge, E_α is energy of α particles.

Regardless of constant, the shape of angular distribution is described as below and shown in fig (2)

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

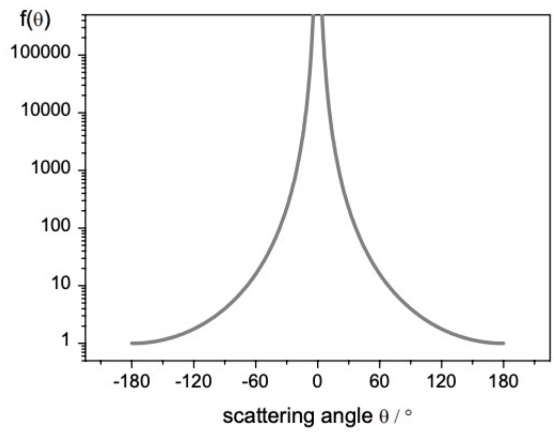

Figure 2: Theoretical slope of scattering rate according to equation.

Each plane angle θ corresponds to cone with aperture 2θ. Therefore the angular differential dθ in 3D should be considered. The spatial scattering rate is given by

$$N\theta = 2\pi.sin(\theta)N_d \tag{3}$$

where $N_d = n/t$, n is count and t is time at particular angle.

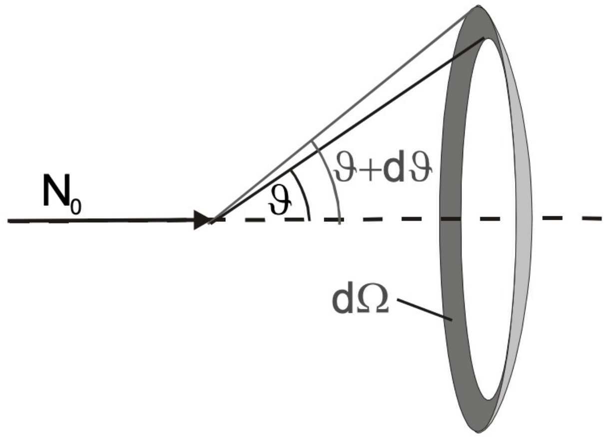

Figure 3: Differential scattering cross section in 3D.

If we compare the scattering rates between two metal foils 1 and 2, at same angle, then

$$\frac{N_1}{N_2} = \frac{c_1.d_1.Z_1^2}{c_2.d_2.Z_2^2} \tag{4}$$

II. EXPERIMENT

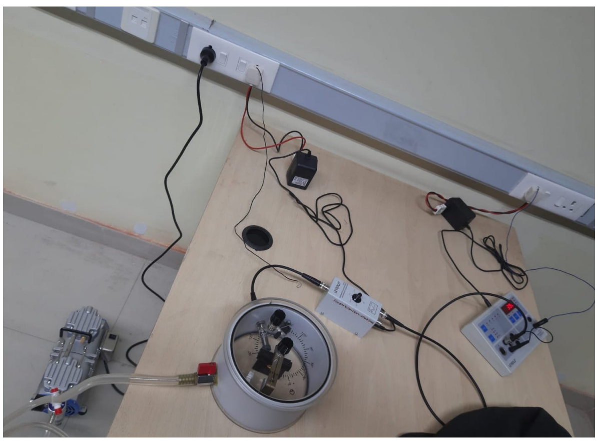

Figure 4: Experimental Setup in Laboratory

Table I: Count for gold foil width=5mm

Time (s)	Angle (deg)	Count	Average Count	Average Count Rate/s	Count rate/s corrected
100	5	3314	3314	33.140	18.14798371
100	-5	4049	4049	40.490	22.17295898
100	10	1824	1820	18.200	19.85735895
		1781			
		1855			
100	-10	3084	2821	28.210	30.77890637
		2656			
		2723			
100	15	459	464.5	4.645	7.553736259
		470			
100	-15	977	972.5	9.725	15.81487301
		968			
200	20	245	237.5	1.188	2.551908928
		230			
200	-20	574	574.5	2.873	6.172933386
		575			
600	25	485	377	0.628	1.668469329
		269			
600	-25	491	398	0.663	1.761407939
		305			
900	30	246	246	0.273	0.858701992
900	-30	390	390	0.433	1.361356817

Table II: Count for gold and aluminium foil width=1mm

Material (1 mm)	Time (s)	Angle (deg)	Count	Average Count	Average Count Rate/s	Corrected Count Rate/s
Au	100	-15	32	31.33	0.3133	0.50954518
			27			
			35			
	100	15	24	20.67	0.2067	0.3360829911
			19			
			19			
Al	1000	-15	85	95.5	0.0955	0.0155302866
			106			
	1000	15	84	84.5	0.0845	0.06578011447
			85			

From table (1), we plot Scattering angle versus rate and fit it with,

$$f(\theta) = \frac{A}{sin^4((\theta - B)/2)} \tag{5}$$

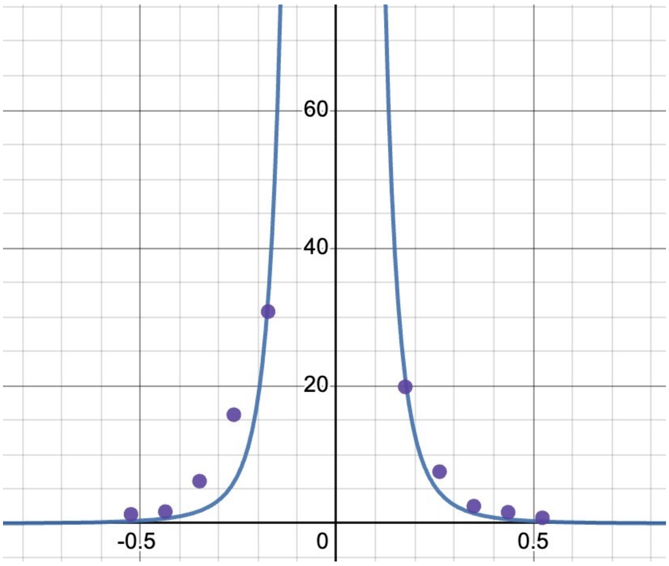

Figure 5: Scattering angle versus scattering rate for gold foil of thickness 5 mm. Note that x-axis is scattering angle in radian. y-axis is scattering count.

The fit parameters were 0.0015 and -0.0094 for A and B respectively. In the above free fit, angles of -5 and 5 degrees were ignored for better fit to the data. Converting B to degrees gives 0.54 degrees.

To find the nuclear charge, we use equation (4) with concentration of both metals are equal

$$Z_{Al} = \sqrt{\frac{N_{Al}.d_{Au}.Z_{Au}^2}{N_{Au}.d_{Al}}} \tag{6}$$

The ratio of thickness of gold and aluminium is 0.25.

From calculations, we found that Nuclear charge of Aluminium is 23.24≈23 , with average count rate for Au being 0.26 and 0.09 for Al. The actual value of Z_{Al} is 13.

The relative error is,

$$\text{Relative Error} = \frac{23-13}{13} \times 100\% = 76.92\% \tag{7}$$

III. CONCLUSION

In this experiment, the angular distributions of scattered particles in Rutherford experiment was studied and fitted with the model. It is seen that most of the counts are read for smaller angles, and as they are increased count value is too low that we had to increase the exposure value to get reasonable count readings. Gold foil was used for different angular counts. In the second part we tried to determine the nuclear charge of aluminium with help of count rate in gold and aluminium. We found nuclear charge of aluminium to be 23 with relative error being 76.92%. This experiment was unsuccessful in determining nuclear charge as many significant errors have contributed to the experiment.

Maintaining vacuum inside the apparatus is essential part of the experiment, any leakage will perturb the setup and give unnecessary counts. Covering the setup with black cloth is important. In the experiment, the discriminator adjustment plays a crucial role in determining count value, where the value should be neither less nor high. The knob of adjustment of scattering angle was damaged and may have lead to sytematic error and offset. Some electrical fluctuations, inefficient vacuum pump and protection of light contributed to error.

IV. REFERENCES

1. SPS NISER Manual
2. Desmos-Graphing calculator
3. `https://www.researchgate.net/figure/Top-Rutherfords-scattering-experiment-with-a-par` `fig1_45868627`