CALCULATION OF KINETIC ENERGIES OF ALPHA PARTICLES AND IMPACT PARAMETERS FOR VARIOUS SCATTERING ANGLES FROM ALPHA SCATTERING EXPERIMENT

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ABSTRACT

The essential idea of Rutherford's theory is to consider the α-particle as a charged mass traveling according to the classical equations of motion in the Coulomb field of a nucleus. We measured the number of alpha particles which emitted from ^{241}Am alpha source from Alpha scattering experimental set up in Physics Department, Monywa University of Research Centre. Gold foil is placed between the detector and the ^{241} Am source. It is observed that the incident particles for small angles are more than for large angles. The kinetic energies of alpha particles are calculated for various angles and impact parameters for various angles. It is observed that the impact parameters for large angles are more than for small angles.

Keywords: Alpha particle, Alpha scattering, ^{241}Am, Gold foil, Impact parameters

INTRODUCTION

The foundations of modern ideas about atomic structure are considered to have been laid by Sir Ernest Rutherford in 1911, with his postulates concerning the scattering of alpha particles by atoms. Two of his students, Hans Geiger and Ernest Marsden (an undergraduate), set outα to measure the number of alpha particles scattered out of a collimated beam upon hitting a thin metal foil. They determined the angular distribution of the scattered particles for several different materials, thicknesses and alpha energies. To their initial surprise, Geiger and Marsden found that some alpha particles were scattered through large angles in atomic collisions. This large angle scattering of alpha particles could not be explained by existing theories. This data lead Rutherford to speculate on the structure of the atom and devise a new" nuclear atom" model. His predictions concerning the characteristics of this nuclear atom were confirmed by the subsequent experiments of Geiger and Marsden with the scattering of alpha particles by thin gold and silver foils.

The essential idea of Rutherford's theory is to consider the α-particle as a charged mass traveling according to the classical equations of motion in the Coulomb field of a nucleus.

The dimensions of both the α-particle and nucleus are assumed to be small compared to atomic dimensions (10^{-5} of the atomic diameter). The nucleus was assumed to contain most of the atomic mass and a charge Ze. On this picture the Z electrons which make an atom neutral would not contribute much to the deflection of an impinging α-particle because of their small mass. Other models had been proposed for atoms at this time (~1911) to account for features such as optical spectra. One of these (Thomson's Model) pictured the atom as a continuous distribution of positive charge and mass with the electrons embedded throughout. This model predicts a very small amount of scattering at large angles compared to the Rutherford theory since the α-particles traversing this atom rarely see much charge concentrated in a large mass.

Rutherford Scattering Formula

The number of alpha particles scattered depending on the scattering angle is

$$N(\theta)=\frac{N_i nLZ^2k^2e^4}{4r^2KE^2Sin^4\left(\theta/2\right)} \qquad (1)$$

The equation (1) is Rutherford scattering formula.

$$N(\theta) \propto \frac{1}{sin^4(\frac{\theta}{2})} \qquad (2)$$

Relation between Impact Parameter and Scattering Angle

The impact parameter is the minimum distance to which the α- particle would approach the nucleus if there were no forces between them.

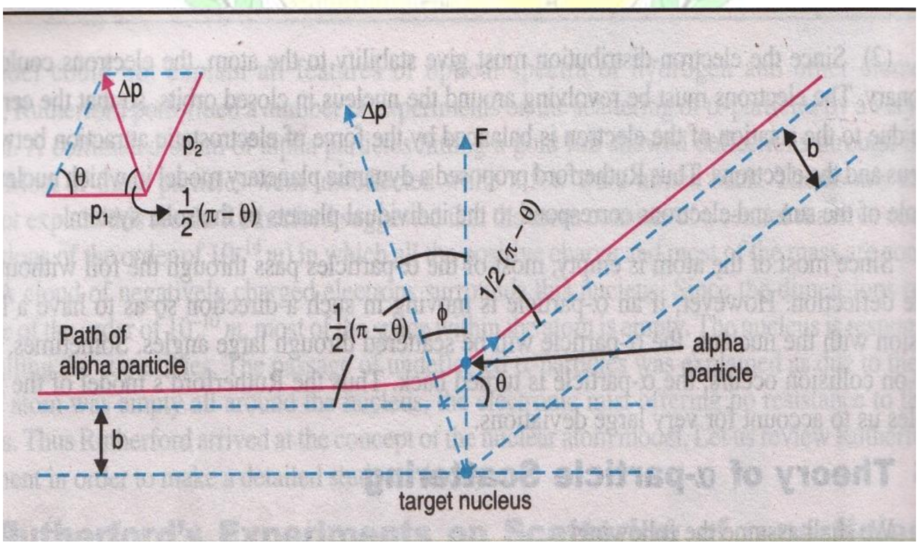


Figure 1. Path of alpha particle and impact parameter

Let $\overrightarrow{p_1}$ and $\overrightarrow{p_2}$ be the linear momenta of the α- particle when it is far from the nucleus before and after the interaction respectively.

$$\frac{p_1^2}{2m} = \frac{p_2^2}{2m} \tag{3}$$

From Newton's second law

$$\Delta\vec{p}=\overrightarrow{p_2}-\overrightarrow{p_1}=\int_0^\infty \vec{F}\mathrm{dt} \tag{4}$$

From Fig (1)

$$\frac{\Delta p}{sin\theta} = \frac{mv}{\sin(\pi-\theta)/2}$$

$$\Delta p = \frac{mvsin\theta}{\sin(\pi-\theta)/2}$$

$$\Delta p = \frac{mv2\sin\left(\frac{\theta}{2}\right)cos\left(\frac{\theta}{2}\right)}{\cos\ \left(\frac{\theta}{2}\right)}$$

$$\Delta p = 2mv\sin(\frac{\theta}{2}) \tag{5}$$

Let $\emptyset$ be the instantaneous angle between $\vec{F}$ and $\Delta\vec{p}$ along the path of the α-particle. Because the impulse $\int \vec{F}dt$ is the same direction as the momentum $\Delta\vec{p}$, its magnitude is $\int \vec{F}\cos\emptyset\, dt$.

$$2mv\sin\left(\frac{\theta}{2}\right) = \int_0^\infty F\cos\emptyset dt$$

$$2mv\sin\left(\frac{\theta}{2}\right) = \int_{-(\pi-\theta)/2}^{+(\pi-\theta)/2} F\cos\emptyset\,\frac{dt}{d\emptyset}d\emptyset \tag{6}$$

The angular velocity o the α- particle about the nucleus is $\frac{d\emptyset}{dt}$. The electric force exerted by the nucleus on the α- particle acts along the radius vector joining them. So, there is no torque on the α- particle and its angular momentum is constant.

$$m\omega r^2 = constant = mr^2\frac{d\emptyset}{dt} = mvb$$

$$\frac{dt}{d\emptyset} = \frac{r^2}{vb}$$

Thus equation (4) becomes

$$\frac{4\pi\epsilon_0 mv^2 b}{Ze^2}sin\frac{\theta}{2} = \int_{-(\pi-\theta)/2}^{+(\pi-\theta)/2}\cos\emptyset d\emptyset$$

$$\frac{4\pi\epsilon_0 mv^2 b}{Ze^2}sin\frac{\theta}{2} = 2\ cos\frac{\theta}{2}$$

$$cot\frac{\theta}{2} = \frac{2\pi\epsilon_0 mv^2}{Ze^2}b$$

$$b = \frac{Ze^2}{4\pi\epsilon_0\ KE}cot\frac{\theta}{2} \tag{7}$$

Where, $\mathrm{K}E = \frac{1}{2}mv^2$ =kinetic energy of α particle.

Experimental Measurement

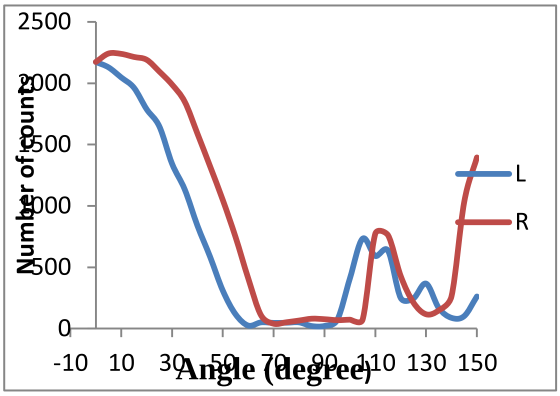
The experimental procedures are as follow. At first, alpha source ^{241}Am is fixed at the position of the source. Fix the gold foil at the place of target. Then the chamber is covered with its lid. Switch on electric pump to pump out the air inside the chamber. Switch off the electric pump, after the vacuum is crated inside the chamber. Place the angle pointer at the position of the desired angle. Adjust the amplifier gain to obtain the reliable number of count. Select the “number of count” button on the scalar unit. Select the counting time “60 s”.Then press the “start” button on the scalar unit.Wait for “60 s” to obtain the number of count which will display on scalar.After 60 s (1 min) the scalar will automatically stop. Repeat the measurement for 10 times. The results are the following tables and figures.

Figure 2. Alpha scattering experimental set up in Physics Department, Monywa University of Research Centre

Figure 3. Various types of alpha Scattering Experiment

Table 1. Different incident, scattered various angles reflected alpha particles for Various angles

Sr:	Angle (degree)		Incident particles		Scattered particles		Reflected particles	
	L	R	L	R	L	R	L	R
1	0	0	2173	2173	495	495	1679	1679
2	5	5	2129	2242	289	464	1839	1778
3	10	10	2047	2239	77	146	1970	2093
4	15	15	1963	2214	71	61	1891	2153
5	20	20	1788	2191	71	30	1718	2160
6	25	25	1648	2095	78	23	1570	2072
7	30	30	1344	1989	27	23	1318	1966
8	35	35	1134	1849	25	31	1109	1818
9	40	40	839	1589	28	52	811	1537
10	45	45	584	1321	34	58	550	1263
11	50	50	309	1047	31	53	278	994
12	55	55	117	746	33	31	84	716
13	60	60	25	409	14	35	11	374
14	65	65	51	110	2	35	49	75
15	70	70	47	40	1	19	46	21
16	75	75	48	52	1	3	47	49
17	80	80	51	66	3	5	48	61
18	85	85	21	81	2	5	19	76
19	90	90	22	77	4	5	18	72
20	95	95	70	69	4	5	66	64
21	100	100	409	73	4	5	405	68
22	105	105	733	73	7	5	726	68
23	110	110	592	773	7	4	585	769
24	115	115	636	762	10	3	626	759



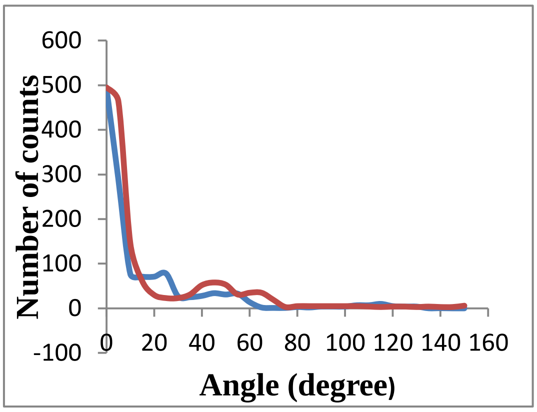


Figure 4. Different (a) incident and (b) scattered alph a particles for various angles

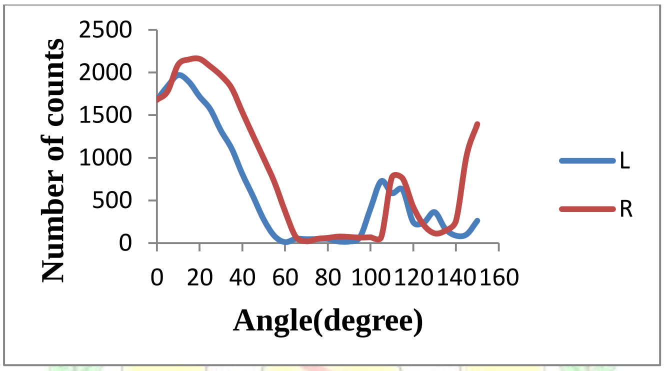


Figure 5. Different reflected alpha particles for various angles

3.1 Calculation of Kinetic Energies of Alpha Particles

We calculated Kinetic energies of alpha particles for various angles by Rutherford alpha scattering experiment. Firstly, we calculated Kinetic energy for angle 5°.

$$(KE)^2 = \frac{N_i n l Z^2 k^2 e^4}{4r^2 N(\theta)\sin^4(\frac{\theta}{2})} \quad (8)$$

$N(\theta)$ = 463.8

N_i = 2241.8

L = 10^{-6}m, e= 1.6×10^{-19}C, Z=79

k = $9\times10^{9}Nm^2/C^2$

r = 2.8cm = 2.8×10^{-2}m

n = 2.689×10^{25} atoms/m^3

KE = 12.16×10^{6}eV

Similarly, we calculated kinetic energies for various angles.The results are shown in table (3).

Table 2. Different the kinetic energies of alpha particles for various angles

Sr:	L			R		
	Angle (degree)	Countrates	Kinetic energies (MeV)	Angle (degree)	Countrates	Kinetic energies (MeV)
1	0	495	0	0	495	0
2	5	289	15.02	5	464	12.16
3	10	77	7.132	10	146	5.43
4	15	71	3.25	15	61	3.74
5	20	71	1.754	20	30	2.96
6	25	78	1.03	25	23	2.145
7	30	27	1.117	30	23	1.456
8	35	25	0.786	35	31	0.901
9	40	28	0.488	40	52	0.492
10	45	34	0.297	45	58	0.343
11	50	31	0.187	50	53	0.261
12	55	33	0.0928	55	31	0.244
13	60	14	0.0563	60	35	0.1441
14	65	2	0.1844	65	35	0.0650
15	70	1	0.2201	70	19	0.0468
16	75	1	0.1970	75	3	0.1200
17	80	3	0.1063	80	5	0.0940
18	85	2	0.0770	85	5	0.09401
19	90	4	0.0494	90	5	0.0830
20	95	4	0.0813	95	5	0.0720
21	100	4	0.1820	100	5	0.0690
22	105	7	0.1713	105	5	0.0641
23	110	7	0.2200	110	4	0.1500
24	115	10	0.1200	115	3	0.2400
25	120	5	0.1000	120	4	0.1500
26	125	4	0.1000	125	4	0.1000

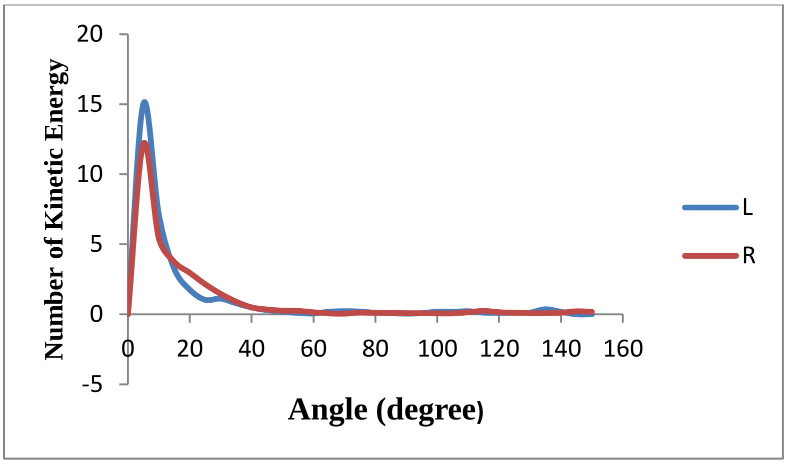


Figure 6. Different Kinetic Energy for various angles

3.2 Calculation of Impact Parameters

We calculated impact parameters for various angles by Rutherford alpha scattering experiment. Firstly, we calculated impact parameter for angle 5°.

$$b = \frac{Ze^2}{4\pi\varepsilon_0 KE}\cot(\frac{\theta}{2}) \quad (9)$$

$\theta = 5°$

$KE = 12.16\ MeV = 1.946x\ 10^{-12} J$

$b = 2.1398x10^{-13} m$

Similarly, we calculated impact parameters for various angles. The results are shown in the following table.

Table 3. Impact parameters for different scattering angles

θ	$(\theta/2)$	$\tan(\theta/2)$	$\cot(\theta/2)$	b(m)
5	2.5	0.0437	22.9037	2.1398E-13
10	5	0.0875	11.4301	2.3919E-13
15	7.5	0.1316	7.5957	2.3077E-13
20	10	0.1763	5.6713	2.1771E-13
25	12.5	0.2216	4.5107	2.3895E-13
30	15	0.2679	3.7321	2.9134E-13
35	17.5	0.3153	3.1715	3.9986E-13
40	20	0.3640	2.7475	6.3455E-13
45	22.5	0.4142	2.4142	7.9978E-13

50	25	0.4663	2.1445	9.3364E-13
55	27.5	0.5205	1.9209	8.9456E-13
60	30	0.5774	1.7321	1.3574E-12
65	32.5	0.6371	1.5696	2.7386E-12
70	35	0.7002	1.4281	7.2445E-12
75	37.5	0.7673	1.3032	2.0390E-11
80	40	0.8391	1.1918	2.0213E-11
85	42.5	0.9163	1.0913	2.2795E-11
90	45	1.0000	1.0000	2.0926E-11

RESULTS AND DISCUSSION

We counted the alpha particles for various angles in 60 s for ^{241}Am source from Rutherford alpha scattering Experiment. We measured alpha particles 10 times for one type. Firstly we measured incident alpha particles from ^{241}Am source for various angles. The measurements are shown in table (1) . Figure 1 (a) is observed that the incident particles for small angles are more than for large angles.

We placed gold foil between the detector and the ^{241} Am source. We also measured scattered alpha particles from ^{241} Am source for various angles. The measurements are shown in figure 1 (b). The reflected alpha particles are obtained as figure (2).

We calculated the kinetic energies of alpha particles for various angles from table (1). The results are shown in table (2) and figure (3).

We calculated impact parameters for various angles. The values of impact parameters are expressed in table (3). It is observed that the impact parameters for large angles are more than for small angles.

CONCLUSION

We measured alpha particles for^{241}Am source by Rutherford alpha scattering experiment. The number of scattered particles of small anglesis more than that of large angles. It is shown that our experiment is agreement with theory. Moreover, we have known the kinetic energies of alpha particles for various angles from measurement of alpha particles by Rutherford alpha scattering experiment. We calculated the impact parameters for various angles. From this calculation we knew the interaction range of reaction for various scattering angles.

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