Rutherford Scattering

1 Introduction

In 1911 Ernest Rutherford discovered the atomic nucleus by scattering α-particles (nuclei of Helium atoms) from a gold foil and observing that some of the α-particles were scattered at backward angles. These results were in startling contradiction with J. J. Thomson's popular "plum pudding" model in which the atom is a spherically shaped mass of positive charge in which negative electrons are embedded. Rutherford concluded that these observations, however, were consistent with a new model in which all of the atom's positive charge and nearly all its mass are concentrated in a small region.

This was the first demonstration of how scattering experiments can be used to study atomic structure, and was the birth of nuclear and particle physics. Today's high energy physics experiments employ these techniques to learn about the structure of known subatomic particles and to discover new particles.

In this lab we will use the 1-MV Pelletron accelerator in room N008 of the Science and Engineering Center to scatter α-particles from thin foils. By measuring the kinetic energies and angles of the scattered α-particles and applying conservation of momentum and energy, we will infer the masses of the target nuclei.

2 Theory

Consider a particle of mass m with initial momentum $\overrightarrow{p_i}$ that collides with another particle of mass M that is initially at rest, as shown in Figure 1. The incident particle scatters at an angle θ with a final momentum $\overrightarrow{p_f}$ while the target particle recoils at an angle ϕ with a momentum $\overrightarrow{P}$.

From conservation of momentum we have

$$\overrightarrow{p_i} = \overrightarrow{p_f} + \overrightarrow{P}. \tag{1}$$

Using the momentum diagram in Figure 2, we can write an expression for the square of the momentum of the recoiling target particle

$$P^2 = \left(\overrightarrow{p_i} - \overrightarrow{p_f}\right)^2 = p_i^2 + p_f^2 - 2p_i p_f \cos\theta. \tag{2}$$

Assuming the collision is elastic, we can apply conservation of kinetic energy and write

$$K_i = K_f + K \tag{3}$$

where K_i, K_f, and K are the kinetic energies of the incident, scattered, and recoil particles, respectively. Inserting the expression for the kinetic energy of a particle in terms of its momentum,

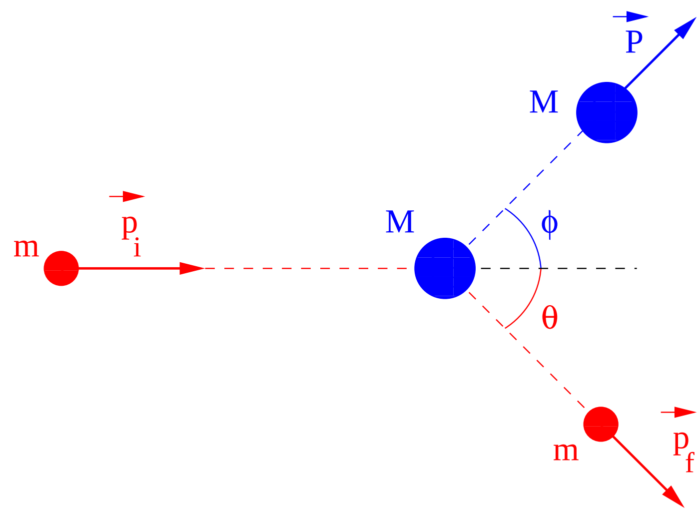

Figure 1: Scattering diagram.

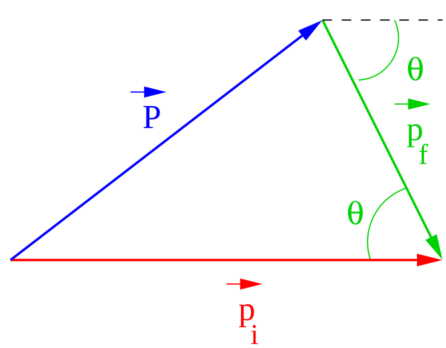

Figure 2: Momentum vector diagram.

$K = p^2/2m$, into Eq. (3) and solving for the square of the momentum of the recoiling target particle we have

$$P^2 = 2M\left(\frac{p_i^2}{2m} - \frac{p_f^2}{2m}\right). \tag{4}$$

Setting Eqs. (2) and (4) equal to each other and performing a little algebra (alright, a lot of algebra), we get an equation for the mass of the target nucleus M as a function of m, K_i, K_f, and θ

$$M = m\left(\frac{\frac{K_f}{K_i} - 2\sqrt{\frac{K_f}{K_i}}\cos\theta + 1}{1 - \frac{K_f}{K_i}}\right). \tag{5}$$

3 Experiment

Using the accelerator in N008b, we will scatter a beam of α-particles of known energy from a target of unknown material. The energies of the scattered α-particles will be measured at two scattering angles with a solid-state detector. The energy spectra of the detected particles will be displayed on the computer screen.

1. Get the energy of the α-particle beam from the faculty member supervising the experiment and record this value as K_i in the Section 4 below.
2. We will begin by measuring an energy spectrum at a scattering angle of $\theta = 160°$. You should see a broad peak and several narrow peaks. The broad peak is due to scattering from nuclei of the primary element in the target while the narrow peaks are from other trace elements. Print a copy of the spectrum for each member of your group. Number each of the narrow peaks in the spectrum. Use the analysis software to determine the energy centroid of each of the narrow peaks and record the results in the K_f column of Table 1 below.
3. The primary peak is broad because the α-particles scatter at various depths in the target, and they lose energy as they travel into the material. Use the high-energy (right) edge of this peak to determine the energy of the α-particles scattered from surface of the primary material. Record this value as K_f for the broad peak in Table 1.
4. Move the detector to an angle of 140°, measure and print an energy spectrum, and repeat the measurements made at 160°. Record the results in Table 2 below.
5. Use Eq. 5 with the values of K_i, K_f, and $m = 4.00\,u$ to calculate M for each peak in Tables 1 and 2.
6. Copy your results for M from Tables 1 and 2 into Table 3 and calculate the average mass $M_{Ave.}$ for each peak.
7. Use the periodic table in your notebook to identify each element in the target material and record the results in Table 3.

4 Data and Results

K_i = ______________ keV

Table 1: Data from energy spectrum at $\theta = 160^\circ$.

Peak	K_f (keV)	M (u)
Narrow peak 1		
Narrow peak 2		
Narrow peak 3		
Narrow peak 4		
Narrow peak 5		
Broad peak		

Table 2: Data from energy spectrum at $\theta = 140^\circ$.

Peak	K_f (keV)	M (u)
Narrow peak 1		
Narrow peak 2		
Narrow peak 3		
Narrow peak 4		
Narrow peak 5		
Broad peak		

Table 3: Average masses and determination of elements.

Peak	$M_{\theta=160^\circ}$ (u)	$M_{\theta=140^\circ}$ (u)	$M_{Ave.}$ (u)	Element
Narrow peak 1				
Narrow peak 2				
Narrow peak 3				
Narrow peak 4				
Narrow peak 5				
Broad peak				