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AN34 Experiment 15

Rutherford Scattering of Alphas from Thin Gold Foil and Other Optional Metal Foils

NOTICE: This legacy experiment requires some equipment that is not available from ORTEC. See the Appendix 15-A for adaptation suggestions.

Equipment Required

- 142B Preamplifier
- 4001A/4002D Bin and Power Supply
- 428 Detector Bias Supply
- 480 Pulser
- 575A Amplifier
- ULTRA™ Ion-Implanted-Silicon, Charged-Particle Detector, Model BU-021-450-100
- EASY-MCA-8K System including USB cable and MAESTRO-32 software (other ORTEC MCAs may be substituted).
- Personal Computer with USB port and recent, supportable version of the Windows operating system.
- Coaxial Cables and Adapters:
  - One C-18-2 Microdot 100-Ω Miniature Cable with two Microdot male plugs, 0.61-m (2-ft) length; to connect the ULTRA detector in the Rutherford Scattering Chamber to the vacuum feedthrough.
  - One C-13 BNC to Microdot Vacuum Feedthrough with female BNC and male Microdot (may already be part of the Rutherford Scattering Chamber).
  - One C-30 Microdot to Microdot Connector with female Microdot on both ends to adapt the C-13 to the C-18-2 (may already be part of the Rutherford Scattering Chamber).
  - One C-24-1/2 RG-62A/U 93-Ω coaxial cable with BNC plugs on both ends, 15-cm (1/2-ft) length. Connects the vacuum feedthrough to the INPUT of the 142B Preamplifier.
  - Two C-24-12 RG-62A/U 93-Ω coaxial cables with BNC plugs on both ends, 3.7-m (12-ft) length.
  - One C-24-4 RG-62A/U 93-Ω coaxial cable with BNC plugs on both ends, 1.2-m (4-ft) length.
  - One C-36-12 RG-59B/U 75-Ω cable, with SHV female plugs on both ends, 3.7-m (12-ft) length.
- TDS3032C Oscilloscope with bandwidth ≥150 MHz.
- ALPHA-PPS-115 (or 230) Portable Vacuum Pump Station.

ORTEC does not sell the following equipment. It must be acquired from another source.

- Small, flat-blade screwdriver for screwdriver-adjustable controls, or an equivalent potentiometer adjustment tool.
- 0.5 to 1 mCi ^{241}Am source with no absorbing window for the alpha emissions. (Half Life: 432 years).
- Metal foils of the nominal, listed thicknesses: Au (1.57 mg/cm^2), Al (0.62 mg/cm^2), Ni (0.87 mg/cm^2), Cu (0.86 mg/cm^2), and Ag (1.1 mg/cm^2).
- Rutherford Scattering Chamber (Requires custom fabrication. See figures 15.2 and 15.3.)

Purpose

In this experiment the scattering of alpha particles by a gold foil will be measured, and the results will be interpreted as experimental cross sections, which will be compared with theoretical equations. Optionally, the dependence of the scattering cross section on the atomic numbers of different metal foils can also be explored.

Introduction

No experiment in the history of nuclear physics has had a more profound impact than the Rutherford elastic scattering experiment. It was Rutherford's early calculations based on the elastic scattering measurements of Geiger and Marsden that gave us our first correct model of the atom. Prior to Rutherford's work, it was assumed that atoms were solid spherical volumes of protons and that electrons intermingled in a more or less random fashion. This model was proposed by Thomson and seemed to be better than most other atomic models at that time.

Geiger and Marsden made some early experimental measurements of alpha-particle scattering from very thin, hammered-metal foils. They found that the number of alphas that scatter as a function of angle is peaked very strongly in the forward direction. However, these workers also found an appreciable number of scattering events occurring at angles >90°. Rutherford's surprise at this observation is captured by his comment in one of his last lectures: "It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a fifteen-inch shell at a piece of tissue paper and it came back and hit you."

Rutherford tried to analyze this angular dependence in terms of the atomic model that had been proposed by Thomson. But, he observed that the Thomson model could not explain the relatively large back-angle cross section that had been found experimentally. Measurements by Geiger and Marsden revealed that 1 out of 8000 alpha particles incident on the platinum foil experienced a deflection >90°. This was in conflict with calculations based on the Thomson model which predicted that only 1 alpha in 10^{14} would suffer such a deflection.

With intense effort, coupled with his unusual physical insight, Rutherford developed the nuclear model of the atom. His calculations, based on Coulomb scattering from the proposed hard central core of positive charge, produced the required 10^{10} increase in cross section found by Geiger and Marsden. Of course, the cross section was very difficult to determine experimentally with the equipment available to these workers (an evacuated chamber with a movable microscope focused on a scintillating zinc sulfide screen). The experimenters had to observe and count the individual scintillation flashes caused by each alpha particle impinging on the zinc sulfide screen. It was only through very careful and tedious measurements that the angular distribution was experimentally determined.

The term, "cross section," mentioned above is a measure of the probability for the scattering reaction at a given angle. From a dimensional standpoint, cross section is expressed by units of area. This seems reasonable since the relative probability of an alpha particle striking a gold nucleus is proportional to the effective area of the nucleus. The concept is similar to throwing a tennis ball at a basketball hanging from a string. The probability of hitting the basketball is proportional to the projected area of the basketball (π times the square of the basketball radius) as viewed from a distance by the person throwing the tennis ball. Cross sections are usually expressed in a unit called "barn," where one barn is $1\text{x}10^{-24}$ cm^2. This is a very small effective area. But, it is not unreasonable, when one considers the small size of the nucleus in comparison to the much larger size of the atom. The term, "barn," originated during the WWII Manhattan project. Experimenters discovered cross sections for slow neutron interactions with atomic nuclei that seemed so large they were colloquially described to be "as big as a barn."

For a Rutherford scattering experiment it is most convenient to express the results in terms of cross section per solid angle. The solid angle referred to is the solid angle that the detector makes with respect to the target, and is measured in steradians, (sr). The solid angle, $\Delta\Omega$, in steradians is simply A_d/R^2, where A_d is the sensitive area of the detector and R is the distance of separation between the detector and the target. The measurement of cross section is expressed in barns/steradian or more conveniently millibarns/steradian, i.e., mb/sr. The cross section defined here is referred to as the differential cross section, and it represents the probability per unit solid angle that an alpha will be scattered at a given angle θ. The theoretical expression for the Rutherford elastic scattering cross section can be simplified to the following formula:

$$\frac{d\sigma}{d\Omega} = 1.296\left(\frac{Z_1 Z_2}{E}\right)^2 \left[\csc^4\left(\frac{\theta}{2}\right) - 2\left(\frac{M}{A}\right)^2\right] \quad mb/sr \qquad (1)$$

Where Z_1 and Z_2 are the atomic numbers of the projectile and target, respectively, E is the energy of the projectile in MeV, M is the mass number of the projectile, and A is the mass number of the target nucleus. For our experiment, ^{197}Au (^{4}He, ^{4}He) ^{197}Au, $Z_1 = 2$, $Z_2 = 79$, E = 5.48 MeV, M = 4, and A = 197. In alpha scattering from gold, it is quite difficult to measure the cross section for scattering angles >90°. The reason for this difficulty is that it takes a prohibitively long period of time to make a measurement at the back angles. To limit the duration of this experiment, only the forward angles will be investigated.

Even for the lightest foil (Al) used in experiment 15.2, the term $2(M/A)^2$ is always quite small compared to $\csc^4(\theta/2)$ and hence can be ignored without much error. To a good approximation, the differential cross section is then given by

$$\frac{d\sigma}{d\Omega} = 1.296\left(\frac{Z_1 Z_2}{E}\right)^2 \csc^4\left(\frac{\theta}{2}\right) \quad mb/sr \qquad (2)$$

Note that the expression in Eq. (2) varies 4 orders of magnitude from $\theta = 8°$ in the forward direction to $\theta = 90°$.

The purpose of this experiment is to show that the experimental cross section can be favorably compared with the theoretical expression in Eq. (2).

POST-EXPERIMENT EXERCISE

The differential cross section in equation (2) tends toward infinity as the scattering angle, θ, approaches zero. Although this may initially seem counter-intuitive, there is a rational physical explanation for that asymptotic behavior. Explain the physical meaning of the infinite differential cross section at $\theta = 0°$.

EXPERIMENT 15.1. Angular Dependence of the Rutherford Cross Section

SAFETY ADVISORY: The ^{241}Am radioactive source used in this experiment has no protective window over the source. Such a windowless configuration is necessary to emit alpha particles with their full energy. Do not touch the active surface of this radioisotope source. Follow all the safety precautions as outlined in “Safe Handling of Radioactive Sources” which can be found in the AN34 Library for Experiments in Nuclear Science on the ORTEC website.

Procedure

1. Set up the electronics as shown in Fig 15.1 and the mechanical arrangement in Fig. 15.2 and Fig. 15.3.

   a. For the cable connections between the ULTRA™ charged-particle detector and the 142B preamplifier, see the description in the list of equipment.

   b. Turn off the power to the Bin and Power Supply. Verify that the 480 Pulser, 428 Bias Supply and the 575A amplifier are all adjacent to each other in the Bin.

   c. Check that the shaping time constant switches accessible through the side panel of the 575A are all set to 1.5 µs.

   d. Connect the power cable from the 142B Preamplifier to the Preamplifier Power connector on the rear panel of the 575A Amplifier. Set the input polarity switch on the 575A Amplifier to POSitive.

   e. Connect the E OUTPUT (Energy output) of the 142B Preamplifier to the INPUT of the 575A Amplifier using a C-24-12 RG-62A/U 93- Ω coaxial cable.

   f. On the 428 Bias Supply, set the POS/OFF/NEG switch to OFF, and turn both ten-turn dials completely counterclockwise (zero Volts). Connect the B OUTPUT of the 428 to the BIAS input of the 142B Preamplifier using the C-36-12 RG-59B/U 75-Ω cable with SHV plugs.

   g. On the 480 Pulser, set the OUTPUT polarity to NEGative. Select OFF with the ON/OFF switch. Set all ATTENUATOR toggle switches to their maximum value. Using a C-24-12 RG-62A/U 93-Ω coaxial cable, connect the ATTENuated OUTPUT of the 480 to the TEST input of the 142B Preamplifier.

   h. Connect the UNIpolar OUTput of the 575A Amplifier to the analog INPUT of the EASY-MCA using a C-24-4 RG-62A/U 93-Ω coaxial cable.

   i. Turn on the Bin power.

   j. Turn on power to the computer supporting the EASY-MCA and activate the MAESTRO-32 MCA Emulator software.

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Rutherford Scattering of Alphas from Thin Gold Foil and Other Optional Metal Foils

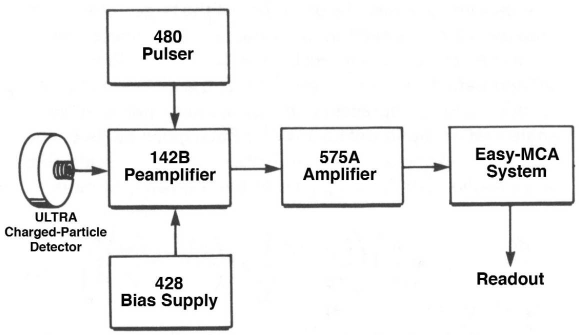

Fig. 15.1. Electronics for the Rutherford Scattering Experiment.

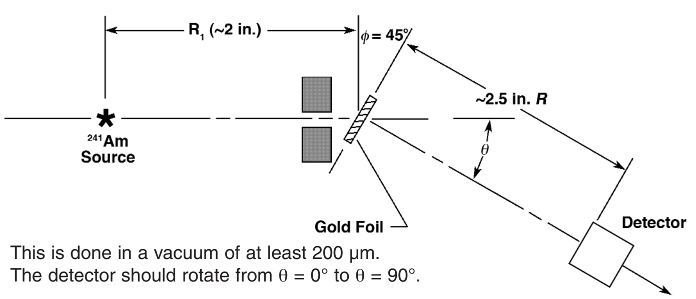

Fig. 15.2. Experimental Arrangement for the Rutherford Scattering Experiment Using a Vacuum Scattering Chamber.

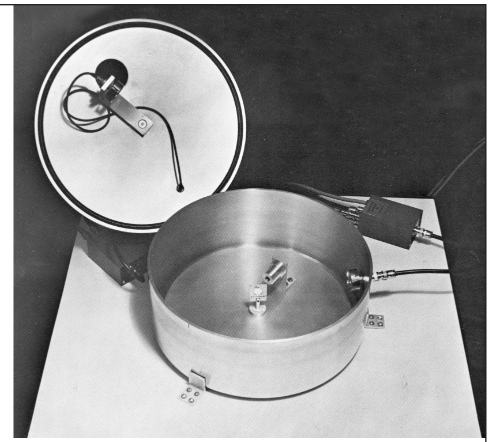

Fig. 15.3. An Example of a Rutherford Scattering Vacuum Chamber.*

*The Rutherford Scattering Chamber incorporates a mount for the ^{241}Am source with source collimator, a centered holder for a thin gold foil, and a silicon, solid-state detector mounted on an arm suspended from the lid. The arm permits detector rotation through the desired scattering angles. The silicon detector mounted in a fixed position is optional, and can be used for coincidence experiments. The collimator aperture limits the solid angle for alpha-particle emission so that the surviving alpha particles (with the foil removed) fall within the sensitive area of the detector when it is located at a 0° scattering angle. The central foil holder permits rotation of the foil with respect to the incident direction of the alpha particles. The chamber requires a fore pump capable of achieving a vacuum below 200 µm. A vent/pump valve is recommended to make pumping and release of the vacuum convenient without turning off the fore pump. A baffle may be needed in the chamber to prevent rupturing the thin metal foils during rapid pump-down and venting.

k. Via the Acquire menu and the ADC tab in the MAESTRO software that operates the EASY-MCA, select the Gate Off option. Choose the analog-to-digital conversion range to be either 2048 or 4096 channels for a 0 to +10 V input. Adjust the Upper Level discriminator to its maximum value and set the Lower Level discriminator as low as possible without causing excessive counting rate on the noise. Under the Preset tab, clear all data fields, and do the same for the MDA Preset option (if supported). Clearing those fields will default to manual control for starting and stopping spectrum acquisition. Familiarize yourself with the software controls for setting up, acquiring and erasing spectra.

2. To prepare for calibrating the system, remove the gold foil, and move the detector to θ = 0°. Pump a vacuum in the chamber to below 200 µm. On the 428 Bias Supply, turn the POS/OFF/NEG switch to POS and adjust the B dial to the voltage specified by the manufacturer of the ULTRA detector. Adjust the gain of the 575A Amplifier so that the peak from the 5.48-MeV alphas from ^{241}Am accumulates in the top eighth of the analyzer.

   NOTE: All further measurements involving detection of the alpha particles requires a vacuum better than 200 µm. To protect the detector, the bias voltage should always be OFF when venting an opening the chamber.

3. Disconnect the 575A UNIpolar OUTput from the EASY-MCA, and connect it instead to the 1-MΩ input of the oscilloscope. Set the horizontal scale of the oscilloscope to 1 ms/cm and the vertical scale to 100 mV/cm. With a small, flat-blade screwdriver, adjust the PZ ADJ on the 575A Amplifier to make the pulses on the UNIpolar OUTput return to baseline as quickly as possible without undershooting the baseline between pulses. For further guidance on the Pole-Zero Cancellation adjustment, consult Experiment 3, the instruction manual for the amplifier, or the introduction to the amplifier product family on the ORTEC website at www.ortec-online.com.

4. Reconnect the 575A UNIpolar OUTput to the EASY-MCA INPUT.

5. Calibrate the MCA with the ^{241}Am alphas and the 480 Pulser in the same manner as outlined for Experiments 4 and 5. Plot the analyzer calibration on linear graph paper, or construct a spreadsheet graph on your own PC. Alternatively, the energy calibration feature of MAESTRO-32 can be employed to make the cursor read directly in MeV. Make sure you turn the pulser off after this calibration.

6. Turn off the detector bias and vent the vacuum. Insert the gold foil in the target position at an angle of 45° to the collimated alpha beam. Keep the detector at $\theta = 0°$. Restore the vacuum and the detector bias voltage. Acquire the spectrum on the EASY-MCA. From the peak position, measure the energy, E_f, for the alpha particles that pass through the gold foil. Calculate the energy loss, ΔE, of the alphas in going through the foil (see Experiment 5); i.e.,

$$\Delta E = E_0 - E_f \qquad (3)$$

where E_0 is 5.48 MeV for the source and E_f is the measured energy after the alphas pass through the gold foil.

EXERCISES

a. From ΔE and the dE/dx information in reference 10, calculate the effective thickness of the gold foil in mg/cm². Keep in mind that the orientation of the foil at 45° increases the alpha-particle path length through the foil by a factor of csc (45°). Consequently, the measured thickness will be larger than the specified mechanical thickness of the foil. Additional data on measured range-energy relationships for alpha particles in various materials is available on the Internet at the link in reference 10.

b. The average energy of alphas experiencing scattering in the foil is

$$E_{av} = \frac{E_0 + E_f}{2} \qquad (4)$$

Determine E_{av} for the measurements made in step 6. Use E_{av} as the value for E in Eq (2), and calculate the values of $d\sigma/d\Omega$ (Theory) from Eq (2) for the angles specified in Table 15.1. Fill in the entire "Theory" column in the table.

c. Plot $d\sigma/d\Omega$ (Theory) versus θ on 5-cycle semilog paper, or create an equivalent spreadsheet graph on your PC. Because of the extreme range of values, the differential cross section requires a logarithmic scale, while the angle should be plotted against a linear scale.

Table 15.1. Comparison of the Theoretical and the Measured Differential Cross Sections.

θ (degrees)	$d\sigma/d\Omega$ (Theory)	$d\sigma/d\Omega$ (Experimental)
10		
15		
20		
25		
30		
40		
50		
60		
70		
80		
90		

d. Calculate n_0, the number of gold target nuclei per cm² from the following formula:

$$n_0 = \frac{(g/cm^2 \text{ of the foil}) \times 6.023 \times 10^{23}}{A} \qquad (5)$$

The value of n_0 will be used at a later time.

e. Calculate $\Delta\Omega$ from the formula

$$\Delta\Omega = [\text{the sensitive area of the detector in cm}^2] / R^2 \qquad (6)$$

Where R is the distance (in cm) from the detector to the gold foil. The sensitive area for the Model BU-021-450-100 ULTRA™ detector is nominally 450 mm².

WARNING: When measuring the diameter of the detector, do not touch the sensitive surface of the detector. Fingers often carry small dirt particles that can easily scratch the thin, ion-implanted window, rendering the detector permanently inoperative. Leaving a finger print on the window can increase the window thickness, thus increasing the energy loss experienced by the impinging alpha particles.

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7. Remove the gold foil and check the alignment of the apparatus by measuring the counting rates for the values in Table 15.2. The counting rate is measured as follows:

a. Acquire a spectrum on the EASY-MCA and set a Region of Interest (ROI) across the entire alpha-particle peak at 5.48 MeV. Read the integrated counts, N, for the peak from the ROI. Read the elapsed Live Time, T_L, displayed by the EASY-MCA software. The counting rate is calculated as

$$I = \frac{N}{T_L} \qquad (7)$$

b. The alpha particles emitted by the radioactive source are distributed randomly in time. Consequently, the number of alpha particles, N, counted in the live time, T_L, is subject to a statistical variation. The expected uncertainty in N is characterized by the standard deviation

Table 15.2. Testing Apparatus Alignment at θ = 0°

Angle θ (degrees)	Counts/s	Angle θ (degrees)	Counts/s
0		0	
1		–1	
2		–2	
3		–3	
4		–4	
5		–5	
6		–6	
7		–7	

$$\sigma_N = \sqrt{N} \qquad (8)$$

Consequently the expected standard deviation in the counting rate, I, is

$$\sigma_I = \frac{\sigma_N}{T_L} = \frac{\sqrt{N}}{T_L} \qquad (9)$$

The expected percent standard deviation in N is equal to the expected percent standard deviation in I, viz.,

$$\sigma\%_N = \frac{\sigma_N \text{ x } 100\%}{N} = \frac{100\%}{\sqrt{N}} = \frac{\sigma_I \text{ x } 100\%}{I} = \sigma\%_I \qquad (10)$$

c. For the data in Table 15.2, count for a long enough time to achieve a 1% standard deviation in I. This will require at least 10,000 counts in the ROI set across the peak.

8. Plot the data in Table 15.2. If the instrument is properly aligned, the data in the table should be symmetric about 0°, with the maximum counts at 0°. If not centered on 0°, a correction for the offset should be applied to the angles in the remainder of the experiment.

9. The number of alphas per unit time, I_0, that impinge on the foil can be calculated by one of the three following methods, depending on the specific geometry of the apparatus.

a. If the source collimator limits the divergence of the alpha particles so that no particles are missing the sensitive area of the detector when the foil is absent, **and** no particles are missing the foil when it is present, then I_0 is the counting rate measured when the detector is centered on the calibrated 0°, as determined from Table 15.2.

b. If the source collimator does not satisfy **both** conditions in method "a", **but** the exposed area of the foil defines the alpha particles that are able to scatter from the foil, then I_0 can be calculated from

$$I_0 = \text{(activity of the source) (area of the foil)} / 4\pi(R_1)^2 \qquad (11)$$

Where the area of the foil is the area projected perpendicular to the beam of alpha particles from the source (see Fig. 15.2). The activity of the source can be determined by the methods outlined in Experiment 4.

c. If none of the conditions in "a" and "b" are met, but the source collimator restricts the alpha particles to illuminating only a portion of the foil area, I_0 must be calculated from equation (11) by replacing the area of the foil with the area of the restricting aperture of the collimator, while substituting the distance from the source to the restricting aperture for R_1.

Check with your laboratory manager to determine which of methods a, b, or c is appropriate for your scattering chamber.

10. You are now ready to measure the cross section. Replace the gold foil (at the angle ϕ = 45°). Set the detector at 10°, and count for a period of time long enough to get good statistics in the peak. Calculate the counting rate, I, at 10°. Repeat for all of the angles listed in Table 15.1. Keep a record of both the number of counts in the peak, N, and the

related live time T_L, in case you need to calculate the statistical uncertainty. It should be obvious from the theoretical cross section that the counting time will have to be increased as θ increases. For the smaller angles, you may be able to get close to a 1% standard deviation. For the larger angles, it will difficult to find enough time to achieve better than a 15% standard deviation. Plan your counting strategy to match the available time.

EXERCISE

f. Calculate the experimental cross section for each of the points in step 10 by using the following formula:

$$\frac{d\sigma}{d\Omega} = \left[\frac{I}{I_0\, n_0\, \Delta\Omega}\right] \quad cm^2/sr \qquad (12)$$

Since 1 barn = 10^{-24} cm^2, the values calculated from Eq. (12) can be converted to millibarns per steradian and entered as $d\sigma/d\Omega$ (experimental) in Table 15.1.

g. Plot the experimental cross section on the same graph as the theoretical cross section.

h. Discuss the degree of agreement/disagreement between the theoretical and experimental cross sections in light of the uncertainties from counting statistics (equations 8, 9 and 10) and any other potential sources of measurement error.

i. What quantitative effect does the angle, $\phi = 45°$, have on the results?

EXPERIMENT 15.2. The Z_2^2 Dependence of the Rutherford Cross Section

In this experiment alpha particles will be scattered from different foils to show the Z_2^2 dependence in Eq. (2). The foils used are aluminum ($Z_2 = 13$), nickel ($Z_2 = 28$), copper ($Z_2 = 29$), silver ($Z_2 = 47$), and gold ($Z_2 = 79$). The student will then plot this Z_2 dependence and show that it does agree with the theory.

Procedure

1. Ensure that steps 1 through 5 in Experiment 15.1 have been completed. Repeat step 6 of Experiment 15.1 for each of the foils. For each foil calculate n_0 as in Experiment 15.1, Exercise d, Eq. (5).
2. For each foil set $\theta = 45°$, and accumulate a pulse height spectrum for a period of time long enough to get at least 1000 counts in the scattered peak. Determine I (the number of scattered alphas per second) for each sample, per the methods used in Experiment 15.1.

EXERCISE

Plot I as a function of $n_0 Z_2^2$ for each sample. The curve should be a straight line. The slope of the line can be determined by equating the two expressions for cross section Eqs. (2) and (12) and solving for the product $n_0 Z_2^2$.

Therefore

$$1.296 \left(\frac{Z_1 Z_2}{E}\right)^2 \csc^4\left(\frac{\theta}{2}\right) \times 10^{-27} = \frac{I}{I_0\, n_0\, \Delta\Omega} \quad cm^2/sr \qquad (13)$$

And hence

$$I = \left[\frac{1.296 \times 10^{-27}\, I_0\, \Delta\Omega\, Z_1^2 \csc^4\left(\frac{\theta}{2}\right)}{E^2}\right] n_0 Z_2^2 \qquad (14)$$

Since every term inside the [ ] brackets is a constant for all foils†:

$$I = K\, n_0\, Z_2^2 \qquad (15)$$

Where the constant, K, is equal to the contents of the [ ] bracket in Eq. (14). Therefore, the experimental intensity should plot as a straight line in this exercise. The slope of the curve is K.

Explain any deviations of the data from a straight line by reference to the uncertainty from counting statistics or any other sources of error in the experiment.

References

1. A.C. Melissinos, *Experiments in Modern Physics*, Academic Press, New York (1966).
2. H. A. Enge, *Introduction to Nuclear Physics,* Addison-Wesley Publishing Co., Massachusetts (1966).
3. R. D. Evans, *The Atomic Nucleus*, McGraw-Hill, New York (1955).
4. B. L. Cohen, *Concepts of Nuclear Physics*, McGraw-Hill, New York (1971).
5. J. L. Duggan and J. F. Yegge, “A Rutherford Scattering Experiment”, J. Chem. Ed., 45 85 (1968).
6. J. L. Duggan, et.al., Am. J. Phys. 35, 631 (1967).
7. C. M. Lederer and V. S. Shirley, Eds., *Table of Isotopes, 7th Edition*, John Wiley and Sons, Inc., New York (1978).
8. G. Marion and P. C. Young, *Tables of Nuclear Reaction Graphs*, John Wiley and Sons, New York (1968).
9. Application notes, technical papers, and introductions to each product family at www.ortec-online.com.
10. Measured data on dE/dx and range-energy relationships for alpha particles in various materials is available from the US National Institute of Standards and Technology(NIST) Physics Laboratory at: http://physics.nist.gov/PhysRefData/Star/Text/ASTAR.html

Appendix 15-A. Finding/Developing the Missing Equipment

The primary reason full equipment support for this experiment has been suspended is the difficulty in obtaining the 0.5 to 1 mCi ^{241}Am source. For the laboratory that is able to find the appropriate alpha-particle source, this appendix provides some guidelines on procuring or developing the missing equipment.

Requirements for the ^{241}Am Source

Ideally, the source should have a construction similar to the Eckert and Ziegler Model AF 241 A2, but with 0.5 to 1 mCi activity. To allow effective collimation of the alpha particles, the diameter of the active area of the source must be restricted to a diameter ≤5 mm. The active material of the source must be thin enough to cause an energy loss that is negligible compared to 500 keV. Hence there must be no significant window thickness over the active surface of the source.

These requirements are formidable to meet, and that is why it is difficult to procure an appropriate source. Lower activities are available in the desired configuration. But, the orders of magnitude lower activities require counting times that are orders of magnitude longer than the typical student lab period.

†This presumes that all the foils have been chosen with appropriate thickness so that $E = E_{av}$ from Eq. (4) is approximately the same for all foils.

Critical Collimator Dimensions

Using the dimensions specified in Figure 15.2 and pictured in Figure 15.3, the distance from the active surface of the source to the center of the scattering foil should be 2 inches (50.8 mm). The distance from the center of the scattering foil to the front of the sensitive area of the detector should be 2.5 inches (63.5 mm).

The collimator is designed to fulfill the condition in step 9a of Experiment 15.1. If the limiting aperture of the collimator has a 3.65 mm diameter and is located as close as possible to the scattering foil, at a distance of 43.0 mm from the active surface of the ^{241}Am source, the collimated beam of alpha particles will illuminate an 18 mm diameter disk on the surface of the charged-particle detector. This leaves a 3 mm margin for misalignment on the 12 mm radius of the sensitive area of the detector. Thus, any misalignment of the collimator and detector must be controlled to less than 1 mm.

Any metal that is convenient to machine is acceptable for fabricating the collimator.

With the above design parameters, the angle of divergence of the collimated beam from any point on the active source area will be approximately 5.8°. The detector sensitive area defines a divergence angle of 21° at the center of the scattering foil. Because the two divergences combine as the square root of the sum of the squares, the effective angular resolution will be approximately ±11°.

Scattering Foils

It is almost impossible to find Nickel foils in the desired thickness. However, adequate supplies of Aluminum, Copper, Silver and Gold foils can be procured from gilding supply retailers. One can search the Internet for convenient sources of supply using the “gilding” search term.

Gilding materials suppliers typically specify the area (length and width) of each metal leaf and the weight per thousand leaves. From those numbers, one can calculate the thickness in mg/cm^2 to compare with the desired thickness. Typically the thickness of the available leaves is below the target value for Experiment 15, and multiple leaves will have to be stacked to reach the desired thickness. Note that the individual leaf thicknesses typically vary by a factor of 1.6 above and below the average thickness for 1000 leaves. Consequently individual leaves will have to be evaluated for thickness, and combined accordingly to achieve the desired thickness.

The desired thickness for each foil is the thickness that causes an energy loss of 354 keV when the 5.48 MeV alpha particle travels through the foil at 90° to the surface of the foil. This energy loss and foil thickness can be checked by inserting the foil in the scattering chamber and measuring the energy loss with the foil set at 90° to the collimated beam, and with the detector located at the 0° position. An energy loss of 354 keV at normal incidence leads to a 500 keV energy loss when the foil is at the 45° angle in the scattering experiment. That offers a reasonable compromise between maximizing the counting rate and minimizing the energy loss.

Plastic frames for mounting 35 mm slides offer a convenient means for supporting and positioning the foils. To secure the ultra-thin foils, it may be necessary to use a piece of conventional 35 mm photographic film (0.14 mm thickness) as a gasket in the frame. To create the gasket, the 35 mm film is mounted in the frame, and the 34 mm x 23 mm window is cut out with a knife. Then, the slide holder is re-assembled with the thin metal foil held in place by the film gasket. The outside dimensions of the slide frame are 50 mm x 50 mm with a thickness in the range of 1 to 3.2 mm.

The thin foils are quite fragile. Therefore, it is advisable to build a considerable stock of replacement foils already mounted in the slide frames and certified regarding thickness. It is also important to limit the vacuum pumping speed on the scattering chamber to avoid rupturing the foil with a sudden rush of air. An orifice in the pumping/venting port is an effective way to provide such protection.

AN34 Experiment 15

Rutherford Scattering of Alphas from Thin Gold Foil and Other Optional Metal Foils

Forecasted Counting Rates

The theoretical equations in Experiment 15 can be used to predict the measured counting rates. With the parameters outlined above, and a 0.50 mCi ^{241}Am source activity, the counting rate with the detector at 0° with no foil present should be circa 7,100 counts/second. The total counting time for Experiment 15.1 is forecasted to be 3.1 hours to achieve 10% counting statistics. Most of this time is consumed at angles between 45° and 90°. The counting times for smaller angles is insignificant.

For Experiment 15.2, the total counting time for 5% counting statistics is expected to be 1.8 hours, if a 30° angle is used. Most of this counting time is consumed on the lighter element foils (Cu and Al). The counting time is much longer, if the 45° angle recommended in Experiment 15.2 is employed. The 30° angle is a more productive option.

Considering the counting times, two 4 hour lab sessions will be required for the two segments of Experiment 15.

Specifications subject to change
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