

Examining the Range and Straggling of Alpha Particles

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Alpha particles, energetic helium nuclei produced through radioactive decay, lose energy rapidly as they traverse matter, resulting in a finite and measurable range. In this experiment we investigated the mean range and straggling of alpha particles in air and helium at atmospheric pressure using an Americium-241 source and a silicon solid-state detector. By measuring the particle count as a function of source-detector separation at several detection thresholds, we reconstructed the shape of the Bragg curve and analyzed how threshold settings influence the observed stopping behavior. Normalizing the data allowed us to identify the onset of source detector superposition, locate the approximate Bragg peak, and determine how sharply the count rate falls near the end of the particle range. We found that lower thresholds produced clearer Bragg features and more reliable range estimates, while higher thresholds tended to obscure the peak and increase apparent straggling. Extrapolating our measured mean ranges to zero threshold yielded estimated ranges of approximately 3.20 ± 0.17 cm in air and 3.66 ± 0.18 cm in helium, consistent with the expectation that helium's lower density leads to reduced stopping power. Although uncertainties in timing, detector alignment, and gas pressure introduced measurable error, the trends in our data align with theoretical predictions and historical measurements. These results demonstrate how macroscopic observations of particle attenuation reflect the underlying physics of charged-particle energy loss.

I. INTRODUCTION

Alpha particles consist of two protons and two neutrons, otherwise known as the nucleus of a helium atom. The difference is in the context of the particle where alpha particles are typically emitted through the nuclear decay processes of much larger radioactive atoms. As these particles traverse through different mediums, they lose energy primarily through Coulomb interactions with the electrons and nuclei of the atoms they encounter. The rate alpha particles lose energy as they traverse depends on the initial energy of the alpha particle as well as the physical properties of the medium they interact with. A consequence of this energy loss is a limited range in which alpha particles can travel through before losing all its energy. Therefore for a source of alpha particles there is a rough distance, typically only a couple centimeters, they travel in a specific medium before coming to a stop. Knowing this range has been crucial for how household items such as smoke detectors function, as well as much more advanced fields like spectroscopy.

Most famously alpha particles were studied and used by Ernest Rutherford for his experiments that lead to the discovery of the nucleus in atoms. In previous experiments examining the range of radioactive particles, a phenomenon known as the

Bragg peak was observed. This shape signifies that an alpha particle requires the most stopping power when it approaches its range. The steep drop off after Bragg peak and the distance it takes from the peak until the plot is zero is the straggling of a particle. Particle interactions depend on many different factors, the uncertainties of which cause small statistical variations in the range of an alpha particle.

In this experiment our goal was to determine the straggling and range of alpha particles in air and in Helium gas. Through this we examined how the stopping power of a medium influences the behavior of charged particles as they lose energy, and how statistical fluctuations in energy loss manifest in measurable variations in particle range. By comparing measurements in air and helium, two gases with significantly different densities and atomic structures, we directly observed how the physical properties of a medium alter both the mean range and the degree of straggling. Comparing our findings with well established theoretical models and historical experimental results allowed us to examine how small differences in the method and system can affect final results. With this, our experiment reinforced the connection between the interaction of particles and macroscopic conditions in our system, demonstrating why careful characterization of the alpha particle range re-

mains important in fields such as detector design and radiation safety.

II. APPARATUS AND METHODS

The setup consists of an isolated tube filled with our desired gas. Inside the tube, Americium-241 acts as a source of alpha particles attached to a rod that connects to a knob outside the tube. This knob allows us to adjust the position of our alpha particle source. On the outer shell of the rod, there is a ruler and marker attached to the rod which allows us to know the position of the source within millimeter precision. The range we can move our source is roughly 6.5 cm, giving us enough room to determine the range that alpha particles travel.

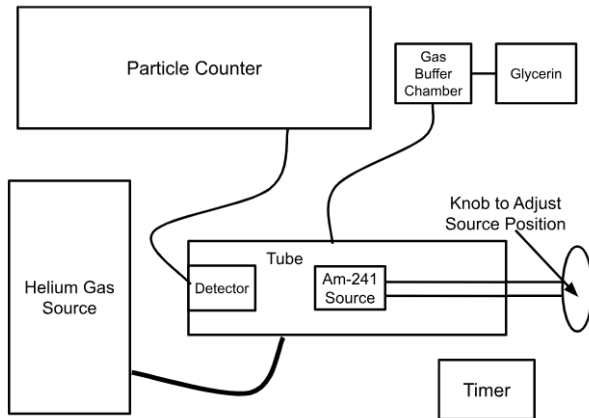


FIG. 1: Diagram of the Setup of our Isolated Tube filled with Gas Medium.

On the opposite end of the tube is our detector connected to the particle counter through a coax cable. The solid state detector is a silicon based detector that functions by applying a reverse-bias voltage in the silicon creating an electric field that collects any electron-hole pairs in the silicon. When alpha particles interact with the silicon atoms they lose the majority of their energy due to Coulomb interactions. This produces anywhere from thousands to over a million electron-hole pairs that are then detected. The counter does not count each individual electron-hole pair, but instead counts the number of incidents of the production of electron-hole pairs. While the counter does not count the number of electron-hole pairs, it has a dial for setting the minimum threshold for detection. This prevents most

noise from accidentally causing the counter to go up but comes at the cost of not being able to detect lower energy alpha particles. Due to this, an accurate alpha particle mean range will have to be determined by performing the experiment for multiple different thresholds. Doing so will let us predict what the mean range should be for the zero threshold by plotting and taking the linear regression of our mean ranges as a function of threshold.

To conduct measurements in helium gas, a gas tank of pressurized helium is connected to the tube. With this we could control the amount of helium added to match atmospheric pressure. A gas buffer chamber and a jar of glycerin were also connected to the tube as a way to exchange the air with the helium gas. The glycerin acts as both a way to slow any helium gas leaking out of the tube as well as a way to verify that the helium gas is flowing into the tube. When the gas was added, the glycerin would bubble up. Measurements were conducted first in air in order to minimize the amount of helium gas present in the tube. Despite these measures, an unknown rate of helium leaks from the gas tank into the tube causing measurements between air and helium gas to be distorted. To mitigate this, the tube was opened up to let air flow in. Once air measurements were completed, the helium gas would be added. Our measurements considered the particle count over the course of a minute, determined by a stopwatch, for several different positions. For demonstrating the Bragg curve with our data, the stopping power of the alpha particles as a function of distance traveled needed to be plotted. Equation (1) demonstrates how to calculate stopping power from the energy of the alpha particles as a function of distance which we can relate to our counts per minute. Another important consideration is that as the source is moved further away the solid angle of alpha particles that shoot out in the direction of the detector decreases. This factor ends up being the distance squared as shown in equation (2). If we were to normalize our counts per minute, we can get a normalized stopping power as a function of distance traveled.

$$S = -\frac{dE}{dx} \propto \frac{N_C}{t} \quad (1)$$

$$N_C \propto N \Delta x^2 \quad (2)$$

III. RESULTS AND DISCUSSION

We took 3 sets of measurements for each gas, with each of these measurements being at a different threshold. In the figure below the normalized particle counts in air are plotted for each of the thresholds. One important observation is how the straggling seems to increase and the Bragg peak shifts closer to the detector as the threshold increases. The rapid increase in the normalized particle count as the separation of the detector and source initially increases is representative of when the detector and source superimpose one another. The moment when the graph shows a plateau is when the true zero position is for the range. This value fluctuated between 0.9 and 1.1 cm for all our measurements, but we took it into account when determining our final mean alpha particle range.

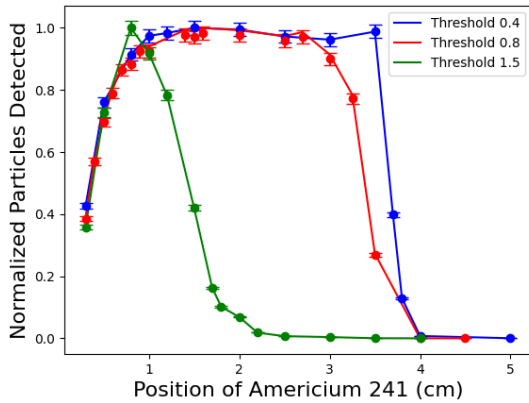


FIG. 2: Normalized and Corrected Particle Count in Air as a Function of Position. Particles counted per minute are plotted with our correction for solid angle.

While the Bragg peak is not as distinguished as in most examples, the steep drop off can be observed in the measurements made for a 0.4 threshold. At the 0.4 threshold the straggling was only 0.5 cm giving us a mean range of 2.75 ± 0.11 cm. When the threshold was set to 1.5 we observed that the Bragg peak likely occurred in the superposition range. The cause of this is likely that the threshold was set too high and as a consequence we were doubtful of the accuracy in the amount of straggling and mean alpha particle range. For the measurements made with a threshold of 0.8, the drop off after the Bragg peak was much more gradual and the straggling ended up being around 1.3 cm. The mean range calculated from this was

2.20 ± 0.10 cm. Plotting the mean ranges versus the threshold gave us an estimate of 3.20 ± 0.17 cm for the range of an alpha particle at the zero threshold. The errors for these experiments were calculated as possible statistical fluctuations in our counts per minute. Since these counts were timed by a separate stopwatch started and stopped by our reflexes, there is a lot of potential error stemming from late and early stops. We conducted several repeated measurements of the same position to determine a standard deviation in counts. Dividing this by the mean gives us a percent error that we can apply to all our particle count per minute measurements as a way to quantify human error. Other forms of error that were considered were with uncertainties in positions since the ruler provided can only be so accurate and small differences can cause larger differences in particle count especially as the detector and source become closer. The exact position of where the superposition begins and where the Bragg peak are located was inconsistent for each plot. We can quantify the uncertainty in the superposition, but to better understand where the Bragg peak is more data points should be taken. This along with possible leakage of helium were some of the pitfalls in our data collection.

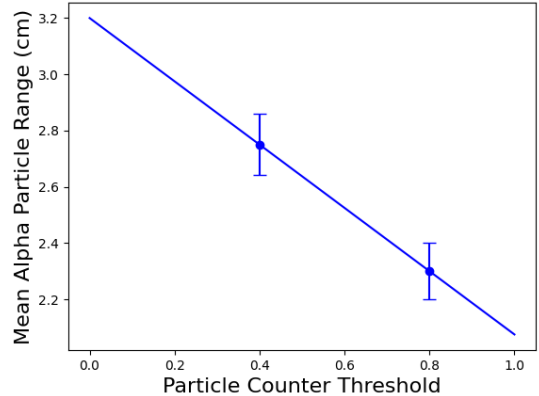


FIG. 3: Linear Regression of Mean Particle Range as a Function of Detector Threshold in Air. Uncertainties consider the Error in Particle Count as well as Uncertainty in Superposition and Bragg Peak Positions

Similar to our results in air, the results in helium gas demonstrated how straggling increases as the threshold energy increases. The same steep drop off present for our measurements with threshold set to 0.4 in air is observed for helium gas. Strag-

gling was still found to be 0.5 cm and the mean threshold was determined to be 2.85 ± 0.16 cm. For the threshold set to 0.8 we observed a much steeper drop off compared to with our air measurements but the straggling was slightly higher at 1.6 cm. We determined the mean range to be 2.30 ± 0.15 cm. Unlike with our air measurements, the Bragg peak seemed to be outside of the range of superposition for a threshold of 1.5. This signifies that in helium gas the alpha particles lose energy less rapidly and therefore should have a longer mean range than in air. As a result of this we felt more confident in the calculations for straggling and mean range with a threshold of 1.5. The mean range ended up being 0.85 ± 0.12 cm and the straggling was 1.8 cm. Plotting these values gave us an estimate of 3.66 ± 0.18 cm for the mean range of alpha particles in helium gas.

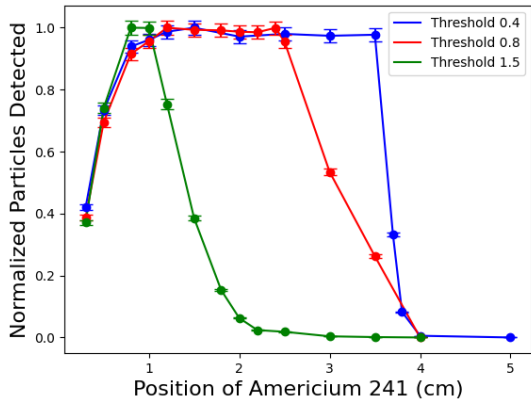


FIG. 4: Normalized and Corrected Particle Count in Helium as a Function of Position. Particles counted per minute are plotted with our correction for solid angle.

While many of the sources of error for these measurements are similar to our air measurements, there are other factors that can cause uncertainties in our data. To ensure that the measurements were taken while the gas inside of the tube was mostly helium, we waited a couple of minutes after we added helium to ensure that the air had been displaced by the helium gas. Another possible source of error was the lack of precision when adding the helium from the tank. The barometer that determined the pressure of the helium gas that would be added to the tube did not provide small enough markers to ensure that the pressure would be at atmospheric pressure. This uncertainty could lead up to roughly a 10% difference in the pressure of

helium gas inside the tube. Unfortunately it was not exactly quantifiable how much this could affect the particle count data with the data we collected, but it could lead to slightly different mean ranges as the density of the gas determines how many random interactions alpha particles have with the helium atoms.

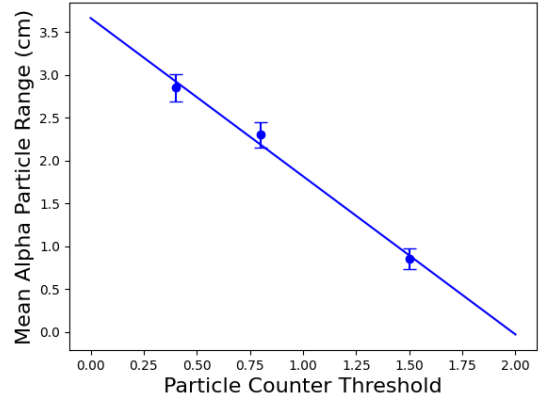


FIG. 5: Linear Regression of Mean Particle Range as a Function of Detector Threshold in Helium. Uncertainties consider the Error in Particle Count as well as Uncertainty in Superposition and Bragg Peak Positions

Together, these measurements highlight the sensitivity of our results to both the detector threshold and the physical conditions of the medium. As expected, lower thresholds consistently produced clearer Bragg curve features and more reliable estimates of the mean range, whereas higher thresholds tended to obscure the onset of the Bragg peak and exaggerate the apparent straggling. The expected range for alpha particles in air is between 3 to 4 cm, with most sources suggesting that it is closer to 4 cm. 4 cm is not in range of our calculated mean alpha particle range and uncertainty, but considering the possible errors that were not quantified, specifically the lack of precision when determining position of the Bragg peak and superposition, could explain why the value was shorter than expected. Despite that, our value was in the larger range of 3 to 4 cm, and as expected, the value of our mean range in helium was larger than in air. Helium gas is less dense than air if kept at the same pressure, therefore less interaction between helium atoms and alpha particles is likely meaning that alpha particles lose less energy per distance traveled in helium.

IV. CONCLUSION

The purpose of this experiment was to measure how alpha particles lose energy in different mediums and to determine how the physical properties of a medium influence both the mean particle range and the degree of straggling. By comparing measurements in air and helium gas at several detection thresholds, we were able to observe clear differences in stopping behavior that reflect the fundamental interactions governing alpha particle attenuation. Our data consistently showed that lower thresholds produced more reliable Bragg curves, while higher thresholds shifted the apparent Bragg peak and broadened the straggling region, demonstrating how detector settings can significantly affect experimental outcomes. Through taking the linear regression of our calculated mean alpha particle ranges at different thresholds, we were able to estimate a mean alpha particle range at the zero threshold. Despite limitations such as timing uncertainty, imprecise positioning, and po-

tential variations in helium pressure, the extrapolated zero threshold ranges were within the expected order of magnitude for both gases. The shorter measured range in air and the longer range in helium align with theoretical expectations based on gas density, validating the overall behavior even if the absolute values were slightly lower than the ideal. To mitigate similar errors found in this experiment for future experiments, a more secure system to prevent leakage of helium into and out of the tube should be implemented as well as a more precise barometer to ensure the amount of helium added matches atmospheric pressure. Taking more data points with smaller intervals closer to the Bragg peak would help define the peak better allowing for more accurately calculated values of straggling and mean range. The same can be said for determining the superposition of the source and detector. When it comes to the range of alpha particles, precision is key, as its use in fields like radiation therapy and detectors requires accuracy in order to save lives.

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