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STOPPING POWER OF ALPHA PARTICLES IN HELIUM GAS

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Abstract

The stopping power and the range of alpha particles emitted from Am-241 source has been investigated in helium gas at different pressures of 0 to 1 bar, using surface barrier silicon detector in the large vacuum chamber. The energy loss has also been obtained at variable distances from 2 to 8 cm. It is observed that as the pressure in a large vacuum chamber increases, the energy loss of the alpha particle decreases. The measured energy loss of alpha particles at lower pressure of 0 bar is less, but at higher pressure of 1 bar is more. As expected from Bethe — Bloch formula, the stopping power of charged particle in helium gas at different pressure was found to increase significantly when pressure is increased. The measured value of stopping power and range were compared with SRIM and theoretical value. The experimental value of stopping power and range was found to be very close to the SRIM and theoretical value. Then, the measured value of range was compared with experimental using the Bragg — Kleeman's rule

Keywords

Range of alpha particle, detector in vacuum chamber, helium gas medium, energy resolution, Bethe theory

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Introduction. The stopping power of charged particles in different materials is important in both applied and theoretical science. It is invaluable in many applied fields of science such as nuclear physics and applications, radiology and radiation damage [1–3] and has been studied by many research groups [4–6]. Heavy charged particles such as alpha particles traversing matter lose more energy by ionization and excitation of atoms [7]. On the other hand, alpha particles are the least penetrating and hence lose more energy by ionizing atoms of its target. This is why alpha particles are the most dangerous to health [8, 9]. Furthermore, L'Annunziata [10] has explored the primary mechanism of interaction for alpha particles as a heavily charged particle under the effect of the Coulomb force. The Coulomb force manifests itself through the positive charge of alpha particles and the negative charge of electrons, placed in the orbitals of the absorber materials. In addition, there is a possibility for interaction between the alpha particles and the nuclei of the material. This process is known as Rutherford scattering. For the purpose of this paper, Am-241 radioactive source was used; the most important and prevalent americium isotope is Am-241. It is made in nuclear reactors, nuclear weapons by irradiating Pu-239 with neutrons. Then, followed by beta decay to Am-241 with a half-life of 14.4 years [11], according to below equation:

$$ {}^{239}_{94}\mathrm{Pu} \overset{2(n,\gamma)}{\rightarrow} {}^{241}_{94}\mathrm{Pu} \overset{\beta-}{\rightarrow} {}^{241}_{94}\mathrm{Am} $$

Since Am-241 isotope releases alpha particles at 5443 keV (13 %) and 5490 keV (84.5 %), decaying to Np-237 which emits gamma ray at 59.5 keV [12–14]. The stopping power is defined to be the amount of energy loss per unit length ($-dE/dx$) suffered by charged particles traversing material due to Coulomb interactions with the electrons of the material and atomic nuclei [15]. It depends on the charge, speed of the projectile and target material [16]. The total energy loss is divided into two parts. The first is nuclear collision called elastic collision process and the second is electronic collision called inelastic collision process [17, 18]. It is also important to consider the range of the alpha particle in any given medium. The range is simply defined as the distance a particle traverses in a medium before it comes to rest [19]:

$$ R = \int_{E_0}^{0} \left(\frac{dE}{dx} \right)^{-1} dE. $$

Also, it would be interesting to add the mass stopping power (keV/(cm^2/g)) dividing by the gas density [20]. SRIM — The Stopping and Range of Ions in Matter programs was used to calculate the stopping power and range into matter [21, 22]. This work is based on the Bethe — Bloch formula [23] which gives the average value of the energy loss dE in a layer dx of the attenuation material. In this work, Energy loss of alpha particles in helium gas at variable pressure and distances using Silicon Surface Barrier Detectors (SSBDs) is discussed.

Methodology. The energy loss of alpha particles through helium gas at different pressures and various distances has been evaluated in a large vacuum chamber. The radioactive source used is Am-241 which emits alpha radiation with energy of 5485.56 keV under vacuum. Using Silicon Surface Barrier Detector which has a resolution of 18 keV for Am-241, an area of 450 mm^2 and 100 μm of depletion depth [4]. The detector and the source were placed inside a large vacuum chamber as shown in Fig. 1. The distance between the source and

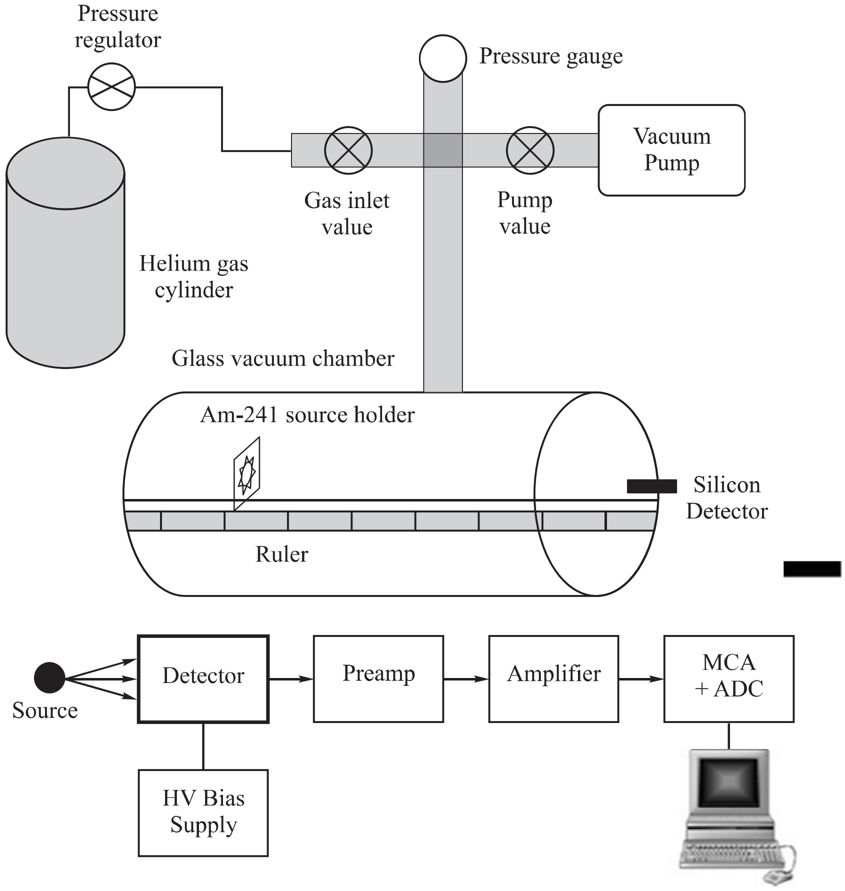

Fig. 1. A diagram on experiment connection

the detector was 1 cm. Now an anode voltage of 50 V was applied for 180 seconds. The values of channel number and Full Width at Half Maximum (FWHM) were recorded to find the Resolution. Moreover, information will be explained in the result and discussion.

The large vacuum chamber was filled with helium gas and the energy of Am-241 beam inside the chamber was measured at various distances from 2 to 8 cm and for several values of the gas pressure. The energy of alpha particles at different pressure in the range of 0.2 to 1 bar was recorded. Then, the pulsar switch was turned on to show the particle energy peak. Half of the original or double of the original pulses were observed. In each pressure drop, the value of the channel number was recorded. From the energy of the source which was 5485.56 keV, half of the original energy and the double of the original energy of the pulses were obtained and were 10 970 keV and 2742.78 keV respectively.

Result and analysis. *Energy Resolution and calibration.* As mentioned in the experimental procedure section, Am-241 was used for studying the energy resolution. Resolution is defined as the ratio between the Full Width at Half Maximum (FWHM) over the location of the peak centroid H_0 [24]. From the data collected, the graph was plotted between biased voltage and resolution. It can be seen from Fig. 2 that an anode voltage of 300 V was chosen as the optimum for the large vacuum chamber. It should be noted that below 100 V, no signal was detected and the voltage above 350 V was not tested.

It is necessary to perform calibration energy using an electrical peak inserted with a pulse at 5486.56 keV. The linear relationship between energies and the channels number was presented below. Figure 3 shows energy as a function of the peak channel number for the large vacuum chamber. A linear relation is generated for the alpha energy with a gradient from below equation:

$$y = 13.693x - 67.84 \text{ channels/keV}.$$

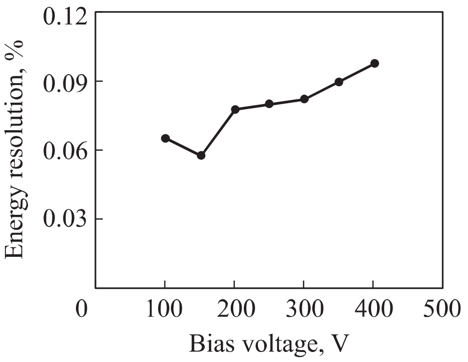

Fig. 2. A graph of resolution against voltage

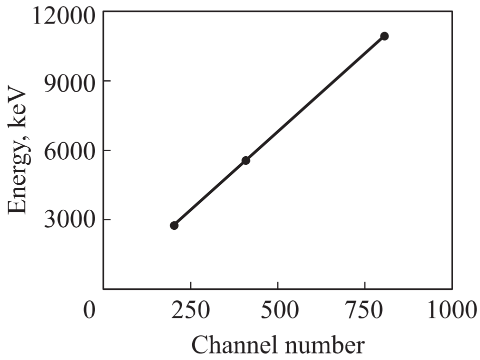

Fig. 3. A graph of linear energy response of the silicon barrier detector (large chamber)

Energy loss of alpha particle in helium gas. The energy loss of alpha particles with various distances source-detector from 2 cm to 8 cm with helium pressure from 0 to 1 bar in the large scattering chamber was measured. Figure 4 shows energy loss of alpha particle in helium gas at various pressures with increasing the distance between the source and the detector. It is observed that as the pressure in the large vacuum chamber increases, the energy loss of the alpha particle decreases. For instance, there are virtually less energy losses since there is almost no molecule of helium gas to interact within the vacuum chamber at pressure 0 bar. Nevertheless, at higher pressure, the large scattering chamber possesses a large amount number of helium gas molecules in the traversing path of the alpha particle and hence the collision probability is higher. As a result of that, energy of the alpha particle loses higher in the medium.

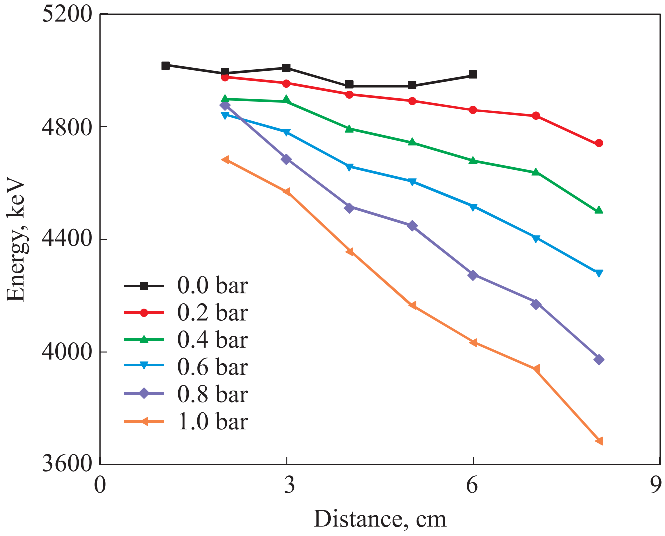

Fig. 4. Energy loss of alpha particle in helium gas at various pressures with increasing the distance (source-detector)

Moreover, it was noticed that the energy of alpha particles at 1 cm far from the detector, a larger amount reached the detector. But at 8 cm far from the detector with the same pressure, a fewer amount reached the detector.

Stopping power of alpha-particle versus the pressure of helium gas. When energy of alpha particles travels through the helium gas, a small amount of their energy is lost. The results of the measured the stopping power and mass stopping power are shown in Table 1. Figure 5 shows a plot of the stopping power of alpha particle in helium gas versus pressure. It can be seen that the stopping power is high at higher pressure of 1 bar but whereas at lower pressure of 0 bar the stopping power is less. Therefore, at any given pressure, the stopping power is lower in helium gas compared to argon and air [25], and hence the range is highest in helium gas. Table 1 also shows the mass stopping power increases with increasing pressure.

Table 1

Stopping powers and mass stopping powers of alpha particle in helium gas at different pressure

Pressure, bar	Stopping power, keV/cm	Mass stopping power, keV/(cm^2/g)
0	10.582 ± 6.58	59 449.4
0.2	35.863 ± 4.52	302 477.5
0.4	65.112 ± 5.33	365 797.8
0.6	92.404 ± 4.46	519 123.6
0.8	141.12 ± 6.84	792 809
1.0	163.85 ± 7.29	920 505.6

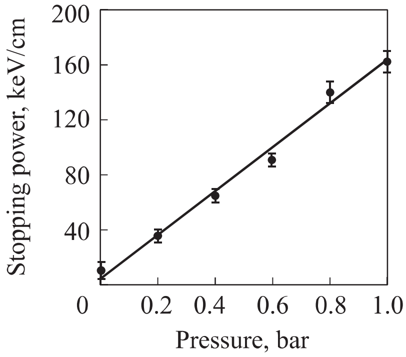

Fig. 5. Stopping power against pressure in helium gas

Figure 6 shows a plot of energy of alpha particles versus projected range in helium gas at room temperature from 10–5500 keV using SRIM [22]. This graph shows that as the energy of alpha particles increase, the projected ranges increase in helium gas.

Table 2 shows the result of the value of the measured range and the stopping power for helium gas. It is clear from Table 2 there is a good agreement between the experimental, SRIM and theoretical values of range and stopping power [26]. The errors in the measured range and stopping power data result from random. The random errors were estimated from the pressure measurement and the uncertainty of the gas temperature. The main error also comes from the increased distance.

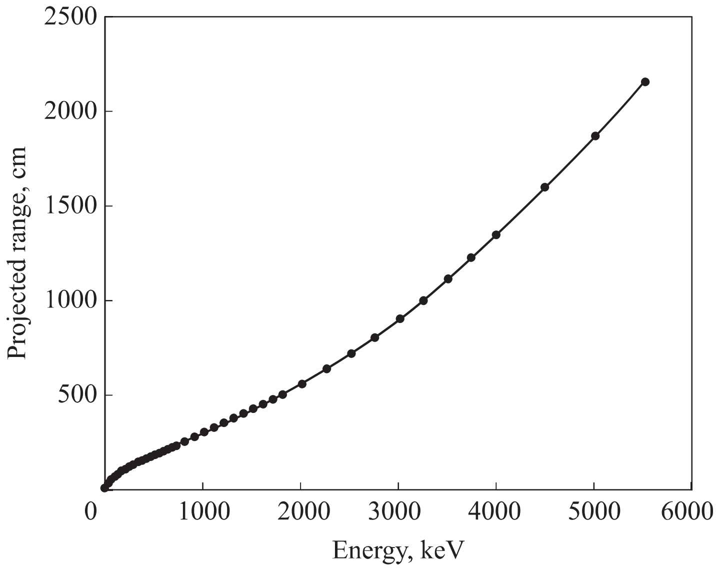

Fig. 6. Projected range against ions energy

Table 2

Value of the experimental, SIRM and theoretical ranges and stopping power in helium gas

Gaseous medium	Range, cm			Stopping power, keV/cm		
	Experimental	SRIM	Theoretical	Experimental	SRIM	Theoretical
Helium	20 ± 0.1	21	21.4	158.49 ± 8.17	160	155

If the range of charged particle such as alpha particle in any medium is known, then Bragg — Kleeman rule can be applied to determine the range of the alpha particle in another medium at room temperature. This rule can be written as [27]:

$$R_{\text{He}} = R_{\text{air}} \frac{\rho_{\text{air}}}{\rho_{\text{He}}} \sqrt{\frac{A_{\text{He}}}{A_{\text{air}}}}, \quad (1)$$

where (the range in air R_{air} = 6 cm, the mass number of air A_{air} = 28.8 g/mol, density of air ρ_{air} = 0.001225 g/cm^3 and density of helium gas ρ_{He} = = 0.000178 g/cm^3) respectively [28]. Hence, applying the simplified Bragg — Kleeman's rule using Eq. (1), the range in helium gas is 15.39 cm that agrees with experimental value.

Conclusion. In conclusion, this work studied the alpha-particle stopping power in helium gas emitted by an Am-241 source, the source inside a large chamber. It was found that the energy loss of alpha particle decreases due to the traversing path of the alpha particle in the medium when the distance between the source and detector decreases.

It was noticed that there is less energy loss at pressure 0 bar, since there is almost no molecule of gas to interact with in the vacuum. Thus, the probability of the interaction could be less. However, by increasing the pressure of a gas, the energy loss of alpha particles increases due to the increase in the amount of interaction with the molecules. Thus, the stopping power for helium gas is lower. Hence, the range of alpha particle is highest because helium has lower density than air and argon. The data showed good agreement between experimental, SRIM and theoretical result. Accordingly, more work could be done by using extremely high pressure, more gases, and other charged particles.

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