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Research Paper

Measuring energy loss of alpha particles in hydrogen gas

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Abstract: The goal of this work is to measure the rate of energy loss (stopping power) of alpha particles emitted from ^{241}Am source as it passes through hydrogen gas which have been investigated using surface barrier detector in vacuum chamber. It was found that the loss energy of alpha particles in hydrogen gas decreases linearly with the increase in the pressure between 0 and 1 bar. The measured value of the range and stopping power were compared with SRIM code and PSTAR. The predicted values based on the experimental, SRIM code and PSTAR show good agreement with for stopping power and rang of alpha particle.

Keywords: SRIM, stopping power, range of alpha particle, mass stopping power.

1. Introduction

Alpha particle loses energy by excitation and ionization of atoms in its path and this loss increases as the distance it traverses increases. A slow alpha particle loses more energy than the fast ones and since the mass of the alpha particle is very much greater than that of the electron, there will be no significant deviation from the original direction of travel [1-3]. Moreover, the energy loss in each collision with an electron will be small. The maximum energy loss by the particle will be equal to the maximum energy that an electron can gain in a collision [4, 5].

Surface silicon barrier detector (SSBD) is a type of semiconductor detector which is made of silicon and doped with a thin piece of impurity atoms to form a p-n junction. When a reverse biased voltage is applied to this detector, a depletion layer is created. Since energy deposition occurs in this depletion layer, its depth must be greater than the particle range to be able to function as a good detector. When the alpha particle enters the detector, it loses energy by raising electrons from the valence band to the conduction band and thus creating electron-hole pairs in the depletion region. The amount of electron-hole pairs created is proportional to the energy of the alpha particle entering the detector. As the applied voltage is increased, the electric field in the depletion region increases and this sweeps away the electrons and hole on the opposite sides of the layer. The resulting charge pulse due to this process produces a signal from the detector which gives information about the amount of energy deposited in the detector. The disadvantage of using this detector is high sensitivity to light [6-9].

Most researchers who investigate the range and stopping power for different media were used the SRIM code [10-13]. Furthermore, Report 49 of the PSTAR [14] measured the stopping and range of ions into a target material. The aim of this work is to investigate the specific energy loss of alpha particles as it traverses media such as hydrogen gas and its range in this media as well. Then the range and stopping power value was compared with SRIM and PSTAR value.

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2. Theoretical calculation

Briefly, the most significant assessment parameters characterizing the energy loss is the stopping power (*S*), range of the alpha particle (*R*) and mass stopping power (*MSP*). Stopping power of matter can be demystified using the concept of Specific ionization which is defined as the average number of ion pairs formed per cm in the track of a charged particle. It is expressed by the following equation [15]:

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

S is positive when the negative sign is used, which is used for particle energy loss as it passes through materials. It is also important to consider the range of the alpha particle in a given medium. The rate at which these charged particle losses its energy when moving thought matter is given by the Bethe-Bloch formula [16]

$$\left(\frac{z\,e^2}{4\pi\varepsilon_0}\right)^2 \frac{4\pi NZ}{m_e c^2\beta^2}\left[ln\left(\frac{2m_e c^2\beta^2}{4\pi\varepsilon_0}\right) - \ln(1-\beta^2) - \beta^2\right] = -\frac{dE}{dx} \quad (2)$$

The range is simply defined as the distance a particle traverses in a medium before it comes to rest. This can be determined from the Bethe-Bloch formula by integration taking our limits of energy over the full energy range as the following equation [17]:

$$\int_{E_0}^{0}\left(\frac{dE}{dx}\right)^{-1} dE = R \quad (3)$$

Furthermore, it would be interesting to define mass stopping power of a material which is the stopping power per unit density (ρ_H= 0.0899 g/cm^3) [18, 19]. It is another useful parameter for energy loss of charged particles of the gas medium traversed which can be written as [20]:

$$\frac{S}{\rho} = MSP \quad (4)$$

3. Experimental procedure

The energy loss of alpha particles through hydrogen gas at different distances and different pressures has been investigated in a small vacuum chamber. ^{241}Am source was placed inside the vacuum.

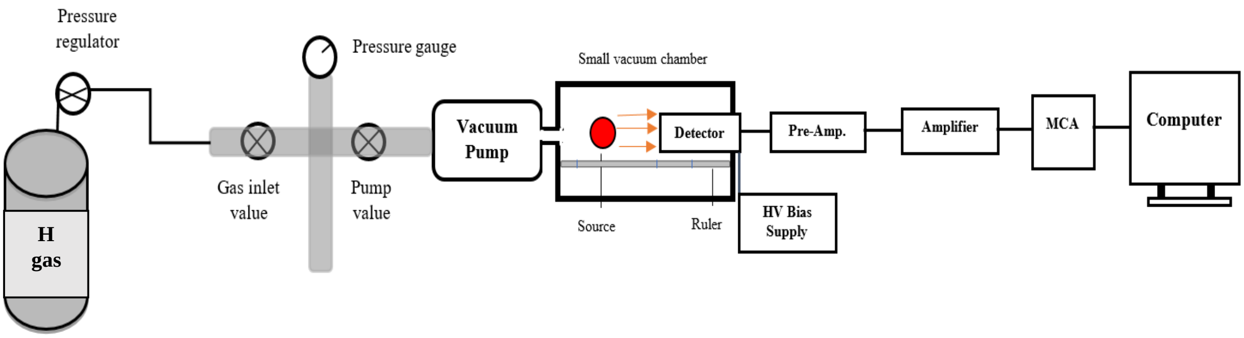

Fig. 1. Schematic view of the experimental setup

This source emits alpha radiation with energy of 5485.56 keV. Now an anode voltage of 50 V was applied for 180 s and the values of channel number, Full Width at Half Maximum (FWHM) and Resolution (FWHM/Channel no) were recorded. The voltage was increased to 350 V in steps of 50 V and in each case, the corresponding values of the channel number, FWHM and Resolution (FWHM/Channel no) were recorded. An anode voltage of 200 V was used throughout the experiment involving this detector. Energy resolution was also studied. This was done by placing the ^{241}Am source and recording the channel numbers. The detector generated outputs whose amplitude is proportional to the energy of the alpha particle. Finally, the vacuum chamber was filled with hydrogen gas and the energy of the source inside the vacuum chamber was measured at different distances from 1 to 10 cm and for 0 to 1 bar of the hydrogen pressure.

4. Result and Discussion

Clearly, figure 2 can be shown that the relation between energy of alpha particle and the centroid is linear. This result is as expected because the signal (counts) from detector is stored in channels with according to the pulse height which is proportional to the energy of charged particle entering the detector. With this calibration, we could determine the energy of the unknown alpha source (or peak). The calculated error was found to be very small to be visible in the energy calibration graph.

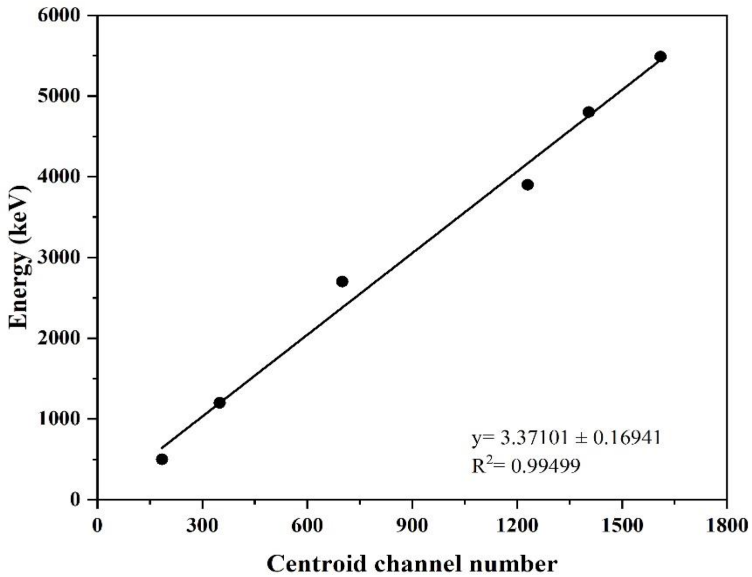

Fig. 2. A graph of energy calibration

The energy loss of alpha particles has been measured with difference distance from 1 to 10 cm at a pressure of 0 to 1 bar in the vacuum chamber. Figure 3 shows energy loss of alpha particle in hydrogen gas at difference pressures with various distance. It is obvious that as the pressure in vacuum chamber increases, the energy loss of the alpha particle reduces. This result was expected based on the theory. There are virtually less energy losses since there is almost no molecule of hydrogen gas to collision within the vacuum at 0 bar. On the other hand, increase in pressure means more hydrogen molecule is present in the chamber. Therefore, when an alpha travel through the hydrogen, it collides with more atoms, frequently and hence, loses more energy. Nevertheless, it can be shown that alpha particles energy at 1 cm far from the detector, a larger amount reached the detector. But at 10 cm far from the detector with the same pressure, a fewer amount reached the detector.

When alpha particles energy travel throughout in hydrogen gas, a tiny number of their energy of the alpha particles loss. The results for the stopping power and mass stopping power are shown in Table 1 that the stopping power is high at higher pressure of 1bar but whereas at lower pressure of 0 bar the stopping power is less. Furthermore, the mass stopping power increase with increase pressure too at a constant energy.

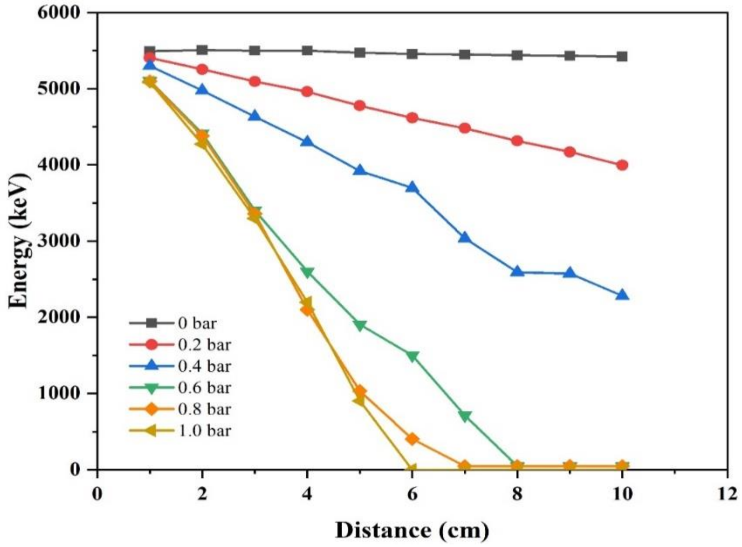

Fig. 3. Energy as a function of pressure in hydrogen gas

Table 1. Stopping power of alpha particle in hydrogen gas at different values of pressure

Pressure (bar)	*S* (keV/cm)	*MSP* (keV. cm^2/g)
0	9.90263 ± 1.03082	110.15
0.2	156.16725 ± 1.19901	1737.12
0.4	352.50682 ± 14.67093	3921.1
0.6	599.32418 ± 47.45099	6666.56
0.8	600.56246 ± 86.1171	6680.34
1.0	603.92648 ± 93.05872	6717.76

Comparison of the alpha particle energy losses in hydrogen gas obtained from data of SRIM code and PSTAR. Figure 4 shows the range of alpha particles in the energy of 100- 5500 keV. The result shows that as the energy of alpha increases, the projected range increases too. Through this comparison, it is observed that the predicted values based on presently considered formulations show good agreement. Table 2 also shows comparison of measured and predicted projected range and stopping power for experimental, SRIM and PSTAR value.

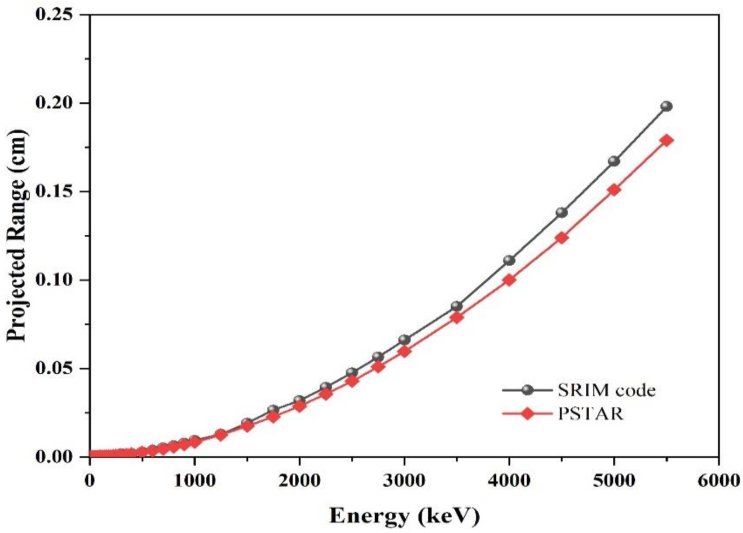

Fig. 4. Comparison of measured and predicted Projected range values, for Alpha particles in hydrogen gas as a function of ion energy

Table 2. The value of the experimental, SRIM [21] and PSTAR [14] value for range and stopping power in hydrogen gas

Gaseous medium	Range (cm)			Stopping power (keV/cm)		
	Experimental	SRIM	PSTAR	Experimental	SRIM	PSTAR
Hydrogen	0.123	0.198	0.1791	9.9	17.43	17.05

5. Conclusions

This paper studied the stopping power of hydrogen gas on alpha particle from the source ^{241}Am. The results were consistent with the Bethe-Bloch formula. On a vacuum chamber, it was found that the energy of alpha decreases linearly with the increase in the pressure between 0 and 1 bar. It is also observed that the amount of alpha particles reaching the detector follows a decreasing behavior as the distance increases. The result based on experimental result, SRIM, ICRU are closely good agreement for both range and stopping power of alpha particle.

Authors' Contributions

Both authors contributed to the study designing and data analysis. HMQ performed the research and wrote the manuscript. Both authors have revised and approved the final draft of the paper.

Competing Interests

The authors declare that they have no competing interests.

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