Probing air pressure in the measurement of stopping powers of the alpha particles in a very small-size detection system

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Abstract

Detection of alpha particles using small detectors in compact system play a vital role in radiation monitoring. This paper aims to examine the stopping power of α- particles emitted by ^{241}Am source via varying air pressure and distances. In the present work, the energy losses of the α-particles are measured at various distances ranging from 1.5 cm to 2.3 cm in steps of 2 mm. Further, the air pressure inside the chamber varied from 10 to 100 kPa. The size of the chamber was very small approx. ½ ℓ in volume. The observations of energy losses were performed using a Si detector, deposited on a PIN photodiode. The dimensions of the detector are 10mm×10mm and 5mm thickness. It has been observed, the stopping power increases with the increasing air pressure inside the chamber. However, the number of α-particles reaching the detecting unit showed decreasing behaviour when the distances were increased, errors due to randomness are considered and incorporated in the analysis. The peak analysis is done with the Gaussian function using the software ORIGIN. The measurements are compared with the SRIM and ASTAR, the measured values are good in agreement with both codes.

Key-word: small alpha detection system, stopping power, mass stopping power, air pressure, Vacuum Chamber

1. INTRODUCTION

The use of technology is booming, subsequently, the requirement for green electricity is increasing day by day. To produce green energy and low cost looking forward to nuclear energies. Agencies advocating nuclear power as a result more reactors are commissioning. Another side many old reactors completed their ages and are decommissioning. Workers enter the highly contaminated zones frequently. Hence, in a reactor site monitoring of contamination of radioactive material is a prime demand of safety, on such production and decommission sites, by knowing the alpha activity in the vicinity, the authority may take preventive action timely and also can choose suitable protective gear. Apart from beta gamma monitoring the information on the alpha emitter is extremely important in a reactor site and/or a working site as the conversion factor to internal exposure changes largely based on the alpha-emitting nuclides [1-4]. However, the measurement of alpha activity directly is difficult in such sites, the difficulty arises due to high activity. There are a few alpha survey meter-based on scintillation (ZnS(Ag)) available but with low detection efficiency, hence alpha particles cannot be detected. Another method of the measure of alpha particles on such sites is the smear method. To keep in mind, further utilization of the low-cost and compact alpha detection systems [5] for such sites, in the present paper under various pressure stopping power (SP) of the alpha particle have been measured and compared with SRIM [11] and ASTAR [12].

The alpha particles primarily interact by coulomb interaction with the orbital electrons within the absorber atom. Entering the medium α-particles undergo interaction at once with many electrons and lose their kinetic energy continuously. Depending upon the closeness of the encounter, the possibility of excitation, conization, and secondary ionization. Whereas heavy charged particles have the least penetrating power compared to high energy photons like X-rays and γ-rays which have the highest penetration power, hence heavy charged particles lose more energy through ionizing of the target atom [6-9]. The pre-eminent parameters identify the energy loss of α-particle is stopping power, range of the α-particle and mass stopping power. The details of the detection of α-particles and measurement of stopping power are given in the following section 2, while the stopping power obtained under various pressures is discussed in section 3.

2. EXPERIMENTAL DETAILS

In the present work, the measurements were done at the Nuclear Education and Research Laboratory of Amity Institute of Nuclear Science and Technology (AINST), India. The detector is supplied by the CSpark[14]. For probing, energy losses alphas, a radioactive ^{241}Am source is considered, which emits radiation with an energy of 5.48 MeV, and the activity of the source is 3654.45Bq, the decay scheme[9] is shown in Figure 1. This source was placed, in the SS chamber and had an equitably tiny volume of roughly ½ litre [12,13]. To observe energy losses, The Si detector implanted on the PIN photodiode was placed in front and parallel to the plane of the source. In an effort, to prevent the incidence of the alpha particle at the detector's boundary, a circular collimator with an aperture of 8 millimetres was placed in front of the detector, otherwise, result in the alpha particles non-linear behaviour. The surface area of the detector utilised is 10mm by 10mm of depletion depth. The simplified view of the experimental setup in which the source and the detector were placed inside a small vacuum chamber is shown in Figure 2. The distance between the source and the detector was 1 cm for finding the best voltage [12-14] of the detector. The stopping powers were measured at various distances of 1.5cm, 1.7cm, 1.9cm, 2.1cm, and 2.3 cm. The effect of various air densities was also taken into account and varied from 0 to 90 kPa [4]. The study collected information on the alpha peak at each distance and used energy calibration to determine the relevant energy. Since there are almost no air particles to interact with in the vacuum when the pressure inside the vessel is 10 kPa, there is very little or no energy loss in this scenario. As a result, the alpha particle will not be facing straggling and will go straight to the detector. Another side, the alpha particle loses energy more quickly as pressure and distance increase as well [15,16]. The measured value of the energy deposited to the detector is given in Table 1.

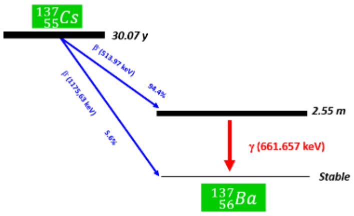

Figure 1. Radioactive Decay Scheme of $^{241}_{95}$Am.

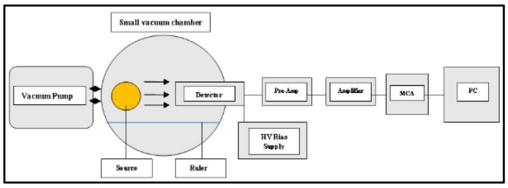

Figure 2. A simplified view of the experimental Setup

Table 1. The measured value energy is deposited by alpha particles at different pressures at various distances.

Pressure (kPa)	10	20	30	40	50	60	70	80	100
Distance (cm)	**Energy Deposited (E2)[MeV]**								
1.5	5.51±0.19	5.42±0.19	5.29±0.19	5.14±0.19	5.00±0.20	4.83±.0.20	4.54±0.21	4.54±0.23	4.21±0.29
1.7	5.47±0.19	5.38±0.19	5.22±0.20	5.04±0.20	4.88±0.21	4.7±0.22	4.34±0.23	4.34±0.24	3.87±0.32
1.9	5.4±0.19	5.32±0.19	5.17±0.19	5.00±0.21	4.81±0.21	4.61±0.22	4.23±0.22	4.23±0.23	3.71±0.28
2.1	5.32±0.20	5.25±0.20	5.08±0.21	4.86±0.22	4.62±0.23	4.41±0.23	3.97±0.24	3.97±0.26	3.48±0.30
2.3	5.28±0.20	5.21±0.20	5.00±0.20	4.82±0.20	4.57±0.21	4.31±0.22	3.79±0.23	3.79±0.24	3.23±0.28

3. Theoretical Calculations: Stopping power

The analysis of the experimental stopping power has been done using two different codes SRIM[11] and ASTAR[12]. Both codes are based on Bethe's stopping-power formula [16]. SRIM is an assortment of programming packages which compute many features of the transportation of particles in the medium [13]. A few of them are the stopping power and Range of particles in the medium. The SRIM uses quick calculations to generate tables of the halting, ranging, and straying dispersion properties for every particle at any energy in any natural goal. Concentrates with complicated multi-facet setups are used in calculations that are more complex. In code ASTAR [12,13] the stopping powers are divided into two categories, below 2 MeV and above 2 MeV. Known as, low energies and high energies alpha, respectively. The evaluation of stopping power at high energies is done by Bethe's stopping-power formula [16]. While, at low energies, fitting formulas [18] are used which are based on experimental stopping power data. A crude approximation of mean excitation energies is considered for the compounds.

The determination of stopping power *S(E)* and Range. The typical energy loss of the heavy ions is dE per unit way length dx is called stopping power. It depends on the energy of the α-particles and on the properties of the medium it penetrates through which can be composed as:

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

Reference to the classical expression for the specific energy loss- "Bethe formula[16]"

$$\frac{dE}{dx} = \frac{4\pi e^4 z^2}{m_o v^2} NZ \times \left[\ln\left(\frac{2m_0 v^2}{I}\right) - \ln\left(1 - \frac{v^2}{c^2}\right) - \frac{v^2}{c^2} \right] \qquad (2)$$

From the above equation, v is the velocity of the particle z charge of the incident particles, N *is* the value of number density, Z atomic number of the absorber material, m electron rest mass, e charge and I Ionization potential of the absorber. The important parameter to be considered is the range of the α-particle in any present medium. The distance travelled from the source point to the target material is defined as the range of the α-particle. The average linear range of alpha particles in the air is given by:

$0.56E = R_{air}$ for $E<4$ MeV (3)

$1.24E - 2.62 = R_{air}$ for $4 \leq E < 8$ MeV (4)

In equations (3) and (4) E is the energy of the particle in MeV.

Table 2. The variation of measured mass stopping power with the chamber pressure.

The pressure inside the chamber (kPa)	Mass Stopping power (MeV/g/cm²)	The pressure inside the chamber (kPa)	Mass Stopping power (MeV/g/cm²)
10	0.908333×10^{-3}	60	0.916667×10^{-3}
20	1.129707×10^{-3}	70	0.942721×10^{-3}
30	1.008403×10^{-3}	80	0.972803×10^{-3}
40	0.847107×10^{-3}	100	0.981544×10^{-3}
50	0.930233×10^{-3}		

4. RESULTS AND DISCUSSION

In a very modest-size detecting device, air pressure was probed while measuring the stopping powers of alpha particles at various distances and time intervals. The measured values of energy deposited by alpha particles at different pressures and various distances are plotted in Figure 3(a)-(f). The energy losses of the particles, emitting from ^{241}Am were determined throughout the study. As the vacuum pressure in the tiny vacuum chamber rises, this causes a significant loss of alpha-particle energy, as illustrated by the results of probing the air pressure of the detector in Figure 3. Because there are almost no air molecules interacting inside the tiny vacuum chamber, the measured energy loss of the alpha-particle at 10 kPa vacuum pressure is now very low. Further, the abundance of air molecules at 100 kPa is higher, resulting in larger energy loss by the alpha particles. There are more air molecules in the path of the particles. At this pressure more air molecules collide, causing the particle to lose more energy. Figure 3. accurately depicts how the energy loss of the -particle rises as the distance between the source and the detector widens. The stopping power was determined by varying the pressure at various distances, as indicated in Table 2. The complete calculated results of alpha particle stopping power in the air have been shown in Figure 4. Respective to the figure the S(E) is lower at a lower pressure 10 kPa, actively the stopping power increases when the vacuum pressure is increased to 100kPa. In the end, the results of the witnessed stopping power and range values, are compared with SRIM and ASTAR values in Table 3.

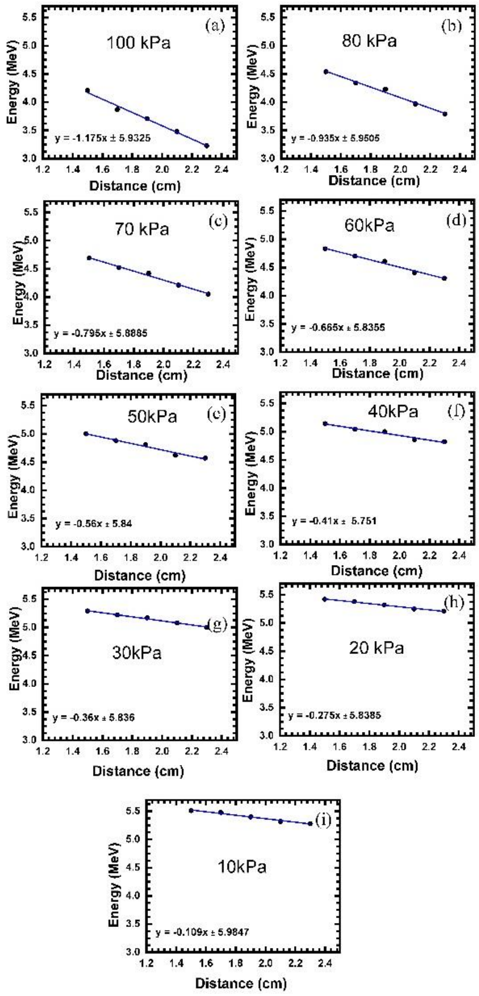

Figure 3. Energy loss of alpha particles in the air as a function of distance for different values of pressure

Table 3. Measured S(E) compared with SRIM[11] and ASTAR[12].

Air	Stopping power (keV/cm)		
	Measured	**SRIM**	**ASTAR**
	1175±35	871	1070

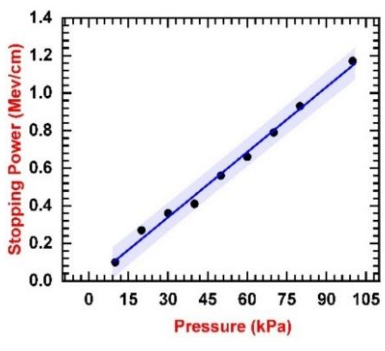

Figure 4. Stopping power verses air pressures

5. CONCLUSION

In conclusion, it is evident that alpha particles tend to go easily across the medium when the pressure is close to the vacuum, this might be a result of the absence of particles with which to interact and expend kinetic energy. Consequently, the alpha particle begins to lose some of its kinetic energy to the gaseous medium's molecules. Similar to how the thickness of a material influences how much alpha radiation is reduced, this energy loss increases as the pressure does. The information indicates that the alpha particle's energy tumbles when pressure increases. In addition, according to the Bethe-Bloch formula, the density is directly related to the rate of energy, *dE/dx*. This indicates that when density rises, stopping power rises as well since a gas's density rises with its molar mass. As demonstrated by the obtained results, the values of the observed stopping power are very near to the ones SRIM and ASTAR are in good agreement. The small-size detection systems can be used and will be cost-effective and it can reduce the cost of detection of alphas at any alpha-prone radiation site.

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REFERENCE

[1] Atomic Radiation and Polymers: International Series of Monographs on Radiation Effects in Materials,1st Edition, Elsevier, Charles by, A., (2016).
[2] Mittal V, et al. Introduction to nuclear and particle physics. 2013. 6. Smith FA. A primer in applied radiation physics. World Scientific Publishing Co Inc. 2000.
[3] Çalişkan, B., Çalişkan, A. C., "Interaction with Matter of Ionizing Radiation and Radiation Damages (Radicals)", Ionizing Radiation Effects and Applications: 135, (2018).
[4] Saied, B. M., Younis, T. A., Shbeeb, A. K., "Mass Stopping Power of Alpha Particles in Liquid Water and Some Gases", AIP Conference Proceedings, (2019).
[5] Yu, K. N., Yip, C. W. Y., Nikezic, D., Ho, J. P. Y., Koo, V. S. Y., "Comparison among Alpha-Particle Energy Losses in Air Obtained from Data of Srim, Icru and Experiments", Applied Radiation and Isotopes, 59(5-6): 363-6, (2000)
[6] Qadr, H. M., "Comparison of Energy Resolution and Efficiency of Nai (Ti) and Hpge Detector Using Gamma-Ray Spectroscopy", Journal of Physical Chemistry and Functional Materials, 3(1): 24-7, (2020).
[7] An ultra-low background alpha detection system with a Micromegas-based time projection chamber, Pan, et. al., Rev Sci Instrum. 93, 013303 (2022).
[8] Alpha particle detection with a planar CdZnTe detector and relative simulations, Radiation Detection Technology and Methods volume 5, 609(2021).
[9] [3]Performance comparison of scintillators for alpha particle detectors, Morishita et. al. Vol. 764, 383 (2014).
[10] Optimization of airborne alpha beta detection system modeling using MCNP simulation, Si Hyeong Sung and Hee Reyoung Kim, Vol. 52 841 (2020).
[11] http://www.srim.org
[12] https://physics.nist.gov
[13] Radiation Detection and Measurement, G F Knoll, John Wiley & Son IVth Edition (2010)
[14] https://csparkresearch.in
[15] http://nucleardata.nuclear.lu.se
[16] Zur Theorie des Durchgangs Schneller Korpuskularstrahlen durch Materie, Bethe, H. A., Ann. d. Physik 5, 325. (1930).
[17] https://dx.doi.org/10.18434/T4NC7P
[18] Reflection of energetic particles from atomic or ionic chains in single crystals,, Varelas, C. and Biersack, J., Nucl. Instr. Meth. 79, 213(1970).