Energy loss and straggling of alpha particles

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The energy loss ($\Delta E$) in an atmospheric gas for light ions such as alpha particles (241Am) of energy 5.48 MeV has been experimentally deliberated in a scattering chamber at different pressures of 4 to 7 mbar. The energy loss has also been obtained at variable distances from 4 mm to 32 mm. The energy loss of alpha particles has been exponentially decreased with increasing pressure. The measured energy loss of alpha particles at higher pressure that is at 7 mbar that is more but at lower pressure of 4 mbar is less. The energy loss of alpha particles increases as distance increases from the source to detector in the scattering chamber. The transmitted energy of alpha particles at lower pressure that is at 4 mbar is high but at higher pressure of 7 mbar is less. The transmitted energy increases as distance between sources to detector decreases. The nuclear and electronic energy loss in the energy range of 1 - 5.5 MeV for an alpha particle is given by SRIM 2008. The projected energy of the alpha particles increases the nuclear and electronic stopping powers decreases exponentially. Further the range of alpha particles is being increased by increasing ion energy. The electronic collision dominates in the higher energy region (MeV) and nuclear collision in lower projectile energies (keV). The energy loss straggling has been found to be increased by increasing pressure as well as increasing the distance between the source and detector in the scattering chamber.

Keywords: Energy loss, Transmitted energy, Energy straggling, Alpha particles

1 Introduction

After the discovery of charged particles from radioactive source the study of interaction of charged particles in matters drags the attraction of many researchers in nuclear physics. The mechanism of interaction of particles with matter depends on the energy, charge state and nature of the particles. The slowing down of light ions in matter continues to be an issue of intense interest, especially in gasses and polymeric targets has been studied and reviewed$^{1-4}$. The first theoretical work in this field was studied by Bohr in 1913, most of the experimental work done on before$^{5-7}$ 1930s. The alpha particle produce by radioactive decay in the energy between 4-10 MeV, the medium used to study their interaction is air. These particles during passage through air lose energy by collision with atoms, and they finally come to rest. The other aspect in variation of the energy transfer to target atoms per unit distance, when mono energetic alpha particles transferred through the medium. Because of variations in the energy transfer, alpha particle energy has a distribution known as stragglng.

Bohr$^8$ prepared the theoretical study and concluded that the square of standard deviation of energy distribution of alpha particles after they have travelled a unit distance in a medium which is directly proportional to number of particles in the path of the alpha energy particle having energy above 2 MeV. Livingstone-Bethe$^9$ and Williams$^{10}$ considered the effects of electron binding on collisions. In the field of energy loss cases of practical interest, the distribution in energy loss is suitably close to the Gaussian distribution. The silicon surface barrier detectors (SSBDs) have already been used in the fields of charged particle detection as a target for coherent interaction in a series of experiments by Bellini et al.$^{11}$

In this paper we discussed energy loss of alpha particle in gas at variable pressure and distances using ORTEC (R-018-450-100) model silicon surface barrier detector connected with 1 K multi channel analyzer. The total energy loss is due to nuclear collision called elastic and electronic collision called inelastic collision processes. The nuclear collision takes place at lower projectile energy which is of the order of keV, in our studies the projectile energy of alpha particles are in the in the MeV region hence the
probability of nuclear collision in this energy range is very less and treats as negligible.

2 Experimental Measurements

The energy loss of alpha particles through the atmospheric gas at different pressures and variable distances has been measured independently in a vacuum chamber. The alpha source Am-241 was placed inside the scattering chamber before creating vacuum in the chamber. The vacuum was created in the scattering chamber, which is connected to a rotary pump and using a knob in positions of HOLD and VENT valves. The alpha source of active area was about 1 mm diameter and it has been deposited on the geometrical centre of the disk. The Am-241 was used as a source for the alpha particles. The rough vacuum was created by using the rotary pump, initially switched on PC and alpha ray spectrometer [PAS-01] the knob position has kept in vent mode. The biasing voltage of 30 V has been applied for the SSBD detector and data acquisition time has set for 100 s then start the acquisition through a window based software ALSS spectroscopy. The data was stored and saved in a computer after the set time is over. Now clear the spectra and start fresh acquisition to the next measurements. The scattering chambers have filled completely with an atmospheric gas/air molecules, and then start to create a vacuum in the scattering chamber using the rotary pump. We recorded the energy spectra of alpha particles at different pressures. Then the peak position in channels and energy has been calibrated using 1 K multi channel analyzer. The energy loss of alpha particles at different pressures in the range of 4 to 7 mbar has been measured.

The alpha particles with initial energy $E_0$ transmitting in the scattering chamber at 4 mbar pressure correspond to signal of incident energy$^{13} E_1$. While, ions penetrating in the air media correspond to signals of energy $E_2$, then, the energy loss ($\Delta E$) of the ions in the air can be obtained as follows:

$$\Delta E = E_1 - E_2$$  \hspace{1cm} (1)

Hence $\Delta E$ is the energy loss of the ions through the matter of air.

3 Results and Discussion

We have measured the energy loss of alpha particles with variable distance from 4 mm to 32 mm at a pressure of 4 to 7 mbar in the scattering chamber. In the vacuum medium, the number of particles in the scattering chamber was decreased by creating more vacuum in the scattering chamber using the rotary pump.

The energy loss phenomena in the electronic collision dominate at higher energy region; this is due to inelastic collision leads to transfer of energy from the projectile to electrons of the target atoms. The energy loss of alpha particles at different pressures of the vacuum medium is shown in Fig. 1. It is observed from Fig. 1 that as the pressure in scattering chamber increases the energy loss of the alpha particle decreases. This was ascribed to the lesser interaction of alpha particles with the medium. At higher pressure, the scattering chamber possesses more number of gaseous molecules in the traversing path of the alpha particle ions and hence the probability of the interaction will be more. As a result, this leads to a higher energy loss of alpha particles in the medium. In another words lower pressure, the scattering chamber possesses less number of gaseous molecules in the traversing path of the alpha particle ions and hence the probability of the interaction will be less. As a result, this leads to a lower energy loss of alpha particles in the medium. Further, it is also observed from Fig. 1 that as the distance between the source and detector decreases the energy loss also decreases due to the traversing path of the alpha particle in the medium decreases.

The transmitted energy of alpha particles is high at lower pressure of 4 mbar but whereas at higher pressure of 7 mbar the transmitted energy is less. This is due to the more number of air molecules present in the scattering chamber as pressure goes up, as a result, the probability of interaction of the alpha particles with these molecules is more and hence that leads to the lesser transmitted energy which is given in Fig. 2. It is also observed that as source distance decreases the transmitted energy increases.

![Fig. 1 – Energy loss versus pressure.](image-url)
Figure 3 shows a plot of nuclear and electronic energy loss, in atmospheric air, as a function of projected energy of alpha particles in the energy range of 1-5.5 MeV using SRIM [Version-2008]. This graph reveals that as projected energy of the alpha particles increases the nuclear and electronic stopping power decreases exponentially. This is due to the interaction mechanism by which the ion can lose energy by elastic collision with the nuclei and by inelastic collision with the electrons of target atoms of atmospheric air media due to increase in the molecules of alpha particles in the traversing path, inside the scattering chamber. This leads to comparison of nuclear stopping power with the electronic stopping power of air molecules for alpha particles that is shown in Fig. 3.

Figure 4 shows energy versus projected range and of alpha particles in atmospheric gas/air at room temperature from 1-5.5 MeV. It shows that as mean range of ions increases as projected energy of alpha particles increases in the air.

The time spent in one state or another will be different for different ions, and thus they will arrive at the detector with different energies due to statistical fluctuations in nature; therefore, the net effect of the capture and loss process is to further broaden the distribution. It is reasonable to believe that charge exchange between alpha particles and the gas/air atoms will be relatively large since they have identical atomic excitation and ionization energies, eventually this leads to an anomalous large amount of straggling. Figure 5 shows pressure versus energy straggling of alpha particle in scattering chamber at 4 to 7 mbar pressure. The energy loss straggling is studied at different distances by keeping source in different slots. It reveals that the straggling width found to be increasing with increasing slot distances. As the pressure in the vacuum chamber increases, the alpha particle energy peaks widen. This is due to energy loss straggling, a process where statistical fluctuations occur in the number of collisions along the path of the particles, amounts to the energy lost per collision.

![Fig. 2 – Transmitted energy versus pressure.](image1)

![Fig. 3 – Nuclear and electronic energy loss versus projected energy.](image2)

![Fig. 4 – Projected range versus ions energy.](image3)

![Fig. 5 – Energy straggling versus pressure.](image4)
5 Conclusions

It concludes that as the distance between the source and detector decreases the energy loss of alpha particle also decreases due to the traversing path of the alpha particle in the medium decreases. In the higher energy region the electronic collision dominates due to collision of electrons to the target atoms. The transmitted energy of alpha particle is high at lower pressure and low at higher pressure it is also observed that as source distance decreases the transmitted energy also increases. In SRIM, as projected energy of the alpha particles increases the nuclear and electronic stopping power decreases exponentially. The mean range of ions increases as projected energy of alpha particles increases in the air. Further the straggling width found to be increasing with increasing slot distances as the pressure in the vacuum chamber increases, the energy spectra of alpha particle is widened.

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References
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