Energy loss and associated higher order moments for swift heavy ions in different absorbers: a systematic study

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Introduction

It is a well known fact that swift heavy ion beams are widely being used in experimental research in various disciplines. In many experiments related to nuclear physics, the data interpretation requires the proper analysis of the recorded energy spectra. In thin absorbers, such spectra are analyzed assuming the shape to be Gaussian in nature [1-2]. However the situation is different in case of thick absorbers. In this situation the shape of such a spectrum deviates from the Gaussian nature [3] and becomes skewed with tailing towards lower energies. The required parameters to analyze the data are energy loss caused by the ion within the absorber and the associated higher moments like straggling, skewness etc. Although a good quantum of information related to the energy loss process for different projectile-target combinations [4-5] are available in the literature but only very limited information is available for straggling, skewness [6-7] etc. In this direction we have carried out some systematic studies for energy loss, associated straggling and skewness for swift heavy ions in different absorbers [8-11].

Experimental Details

The experimental measurements for energy loss, straggling and skewness for heavy ions covering Z=6-29 in polymers like Polyetylene terapthalate (PET), Polyethylene napthalate (PEN) etc. were carried out utilizing the pelletron accelerator facility at Inter University Accelerator Centre (IUAC) New Delhi, India. From the recorded energy spectra of various ions after crossing the varying thicknesses of polymeric foils, the average energy loss within the absorber foil from the shift in the centroids of the recorded spectra w.r.t the spectrum without any absorber foil and associated straggling and skewness in terms of energy loss ΔE by the individual ions and the average energy loss <ΔE> are determined, in the light of the following expressions.

Straggling $$\delta E = \left\langle \left(\Delta E - \left\langle \Delta E \right\rangle\right)^2 \right\rangle$$

Skewness $$\gamma = \frac{\left\langle \left(\Delta E - \left\langle \Delta E \right\rangle\right)^3 \right\rangle}{\left\langle \left(\Delta E - \left\langle \Delta E \right\rangle\right)^2 \right\rangle^{3/2}}$$

Results and Discussion

As an illustration, Fig.1 presents a typical spectrum for Si (36.55MeV) ions after crossing the varying thicknesses of PEN absorber foils with maximum energy loss limit ΔE/E ~70%.

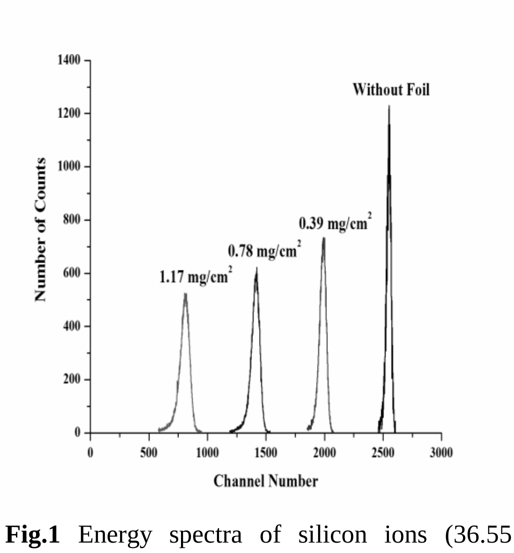

Fig.1 Energy spectra of silicon ions (36.55 MeV) after crossing through varying thicknesses of PEN ($C_7H_5O_2$) polymeric foil.

Fig.1 clearly indicates that with the increasing thickness of the absorber foil, the spectrum becomes asymmetric about the mean with tailing towards the lower energy side. Such asymmetry which can be quantified in terms of skewness enhances with increasing thickness of the foil. In order to account for the contribution of initial broadening in the spectrum due to incident ions and the asymmetry observed in the energy loss profile of transmitted ions after crossing a given thickness of the absorber, the method based on two piece normal distribution (joined half portion) is followed [6]. In this method the standard deviations of the lower energy and higher energy parts of the spectrum from the peak position are deduced separately for the transmitted ions and finally after taking into account the initial broadening due to the incident ions, the various quantities of interest i.e. straggling, skewness etc. are determined. Based on the results of our measurement for Z=6-29 in different polymeric absorber foils of varying thicknesses within fractional energy loss ~ 10-70%, the following inferences are deduced:

a) The measured experimental values for energy loss are in good agreement with the calculated values based on the approach [12, 13] involving the degree of capture of the electrons and shielding provided by the captured electrons to the nucleus for effective charge parameterization.
b) Bethe-Livingston formulation [14] extended to thick targets after suitable modification is well applicable for the calculations of collisional energy-loss straggling even up to fractional energy-loss limit $\Delta E/E$ ~ 70%.
c) The magnitude of skewness increases with increasing ion velocity and with increasing Z for the fixed value of fractional energy loss for these ions.

Conclusions

It can be concluded that the various parameters associated with energy loss due to its statistical nature i.e. straggling and skewness etc. may contribute towards the precise analysis of the data in ion beam based experiments especially involving thick targets besides the fundamental importance of the study. More experiments needs to be carried out in this direction.

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