Behavior of secondary α particles produced from relativistic heavy-ion collisions

P. L. Jain, M. M. Aggarwal, G. Das, and K. B. Bhalla
High Energy Experimental Laboratory, Department of Physics, State University of New York at Buffalo, Buffalo, New York 14260
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The interaction mean free paths of α particles in fragments emitted from two heavy-ion beams of ^{40}Ar and ^{56}Fe, at an energy of $\sim 2A$ GeV have been measured and were found to be the same, within statistical errors, at all distances from their production points.

[NUCLEAR REACTIONS Ar (or Fe) $+ E_m \rightarrow \alpha + X$ and mean free path of α.]

Recently[1,2] in heavy-ion collisions accelerated at an energy ~ 2 A GeV at the Bevalac, an unusual number of secondary interactions of projectile fragments (PF) with charge $Z \geqslant 3$ are observed near the point of the primary interactions. This leads to anomalously shorter mean free paths (mfp) for these fragments within the first few centimeters of their production than those at larger distances where the mfp's observed are normal. In such investigations, statistics of PF's of higher charges is a problem. To overcome this difficulty, the analysis of PF's was based not only on individual charges but also on a group of charges taken together. But in order to understand the cause of an anomalous effect, we should try to see how this effect changes as a function of charge of the projectile fragments; and for that one needs good statistics of individual charges, which is rather difficult for higher Z values. But from cosmic ray studies[3] of heavy primaries, we know that the fragmentation of heavy primaries into α particles is very common and on the average we observe more than one α particle per collision. Thus one can have reasonable statistics for α particle production to check this short mfp component within the first few centimeters. Recently Friedlander *et al.*,[4] used He PF from 1.88 A GeV ^{56}Fe and their preliminary data show the existence of a short mfp component up to about 3 cm path lengths from the point of primary interactions. Our experimental results on He PF disagrees with them.

In order to examine the anomalous behavior of PF's of charge two (α particle), we used two small stacks of Ilford G-5 emulsions exposed to ^{56}Fe and ^{40}Ar beams at about 2 A GeV parallel to the pellicles surfaces.[2] Each pellicle was scanned by along-the-track method.[5] We thus found about 5000 primary interactions from which 3393 relativistic tracks of $Z = 2$ emitted from the primary interactions within 0.1 rad forward cone were followed until they either interacted or left the stack. Our sample of α particle contains both the helium isotopes, i.e., ^4He and ^3He in the ratio[6] 1 : 0.31 and we observed 695 secondary He interactions. The He fragments are easily identified by their distinct grain intensities (~ 4 g min and for relativistic tracks it should not change within 2 cm of its path length followed from its production point) or by their δ-ray density measurements.[7] Low velocity $Z = 1$ secondaries with similar grain densities are easily discarded by their display of large multiple scatterings. From the production point of He fragment, the distance T available for its interaction in emulsion (the potential length) or if it interacted, the distance S to the interaction point was recorded. The mfp of interactions in nuclear emulsion of a homogeneous beam of nuclei is given by $\lambda = (\sum_i d_i)/N$, where $\sum_i d_i$ and N are the total path length of both interacting and noninteracting tracks and the number of interactions of the i particles within that path length interval, respectively. This estimate is therefore independent of stack size or of the location of the track segments in which λ is measured. The number of interactions observed in different interaction distances L up to a distance of 10 cm are shown in Fig. 1(a). The mfp for He fragment for $L \leqslant 3.0$ cm is 19.5 ± 1.0 cm which is not different within the statistical errors from 20.3 ± 1.2 cm for $L > 3.0$ cm. We show in Fig. 1(b) the mean free path of secondary He fragments as a function of distance L from the point of the primary interactions, which is computed by dividing the total track length in a certain path length interval by the number of interactions observed in that interval. Our experimental results indicate no statistically significant deviations from the primary He data shown by the dotted line in the figure.[8–10] Thus we observe no anomalously short mean free path component in the first few centime-

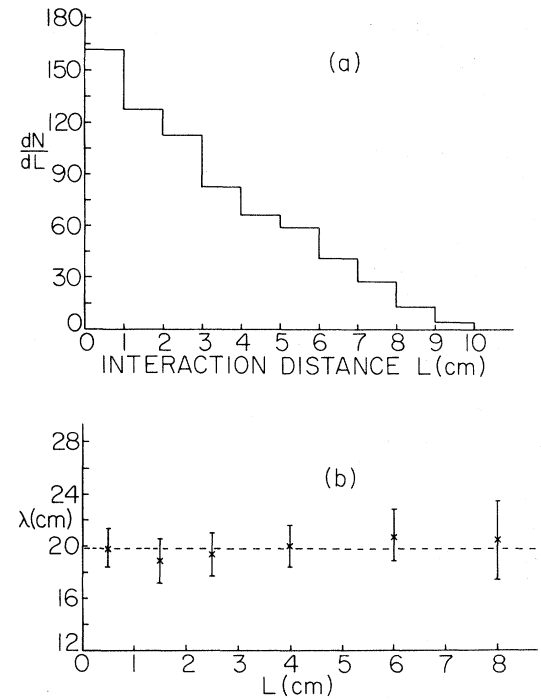

FIG. 1. (a) Distribution of interaction distances L for He fragments. (b) Experimental observation of mfp (λ) of He fragments at different path lengths L from the origins of projectile fragments. Dashed line is primary He beam value from Refs. 8–10.

ters of secondary He tracks as was observed in secondary fragments of $Z > 3$. The scanning of the first few centimeters of the track lengths of PF's produced from the interaction point is very crucial for anomalous nuclei. So we rescanned the data of PF's up to 5 cm of their track lengths under 100 × objective (just as before) and we found the scanning efficiency of He-fragment interactions in emulsion better than 97%. Our data on He-fragment samples do not show an anomalous effect.

In order to see whether different types of targets in emulsion have any influence on the observed mfp, we divide the primary interactions into categories of light (i.e., $N_h \leq 7$, interactions with C, N, O elements where N_h denotes the number of heavy trackes with $\beta \leq 0.7$) and heavy (i.e., $N_h > 7$, interaction with Ag, Br elements) targets. We observe no difference in mfp from either category within their statistical errors. Furthermore, we observed no difference in the percentage number of white stars ($N_h = 0$) present in distance $L \leq$ and > 3 cm. We find that the behavior of relativistic He PF (secondary beam) is the same as the primary He beam. The overall mfp in this experiment is 19.8 ± 0.75 cm which is comparable to values of mfp's of primary He beam of 19.3 ± 1.0, 20.2 ± 1.7, and 19.2 ± 0.7 cm in Refs. 8–10, respectively. This is different from 21.8 ± 0.5 cm as given by Friedlander *et al.*[4] We may point out that the percentage of production of white stars in the present experiment is about 14% while in Ref. 6 it is 10% in He and 13.6% in ^{12}C beams. It is possible to miss white stars ($N_h = 0$) to give a larger value of mean free path. Scanning of He-fragment interactions in emulsion should be done very carefully with 100 × objective.

In conclusion, we have observed no "anomalous" behavior of the He fragments in their mean free path within the first few centimeters from their production points. It will be very important to repeat this experiment with other PF's with monocharges higher than two.

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