Search for anomalous interactions in a photographic emulsion bombarded with ^{12}C and ^{22}Ne nuclei at 4.1 GeV/c per nucleon

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Anomalous interactions have been sought in a photographic emulsion bombarded with ^{12}C and ^{22}Ne ions at a momentum of 4.1 GeV/c per nucleon. The results of this search are reported. An analysis of 2034 fragments with charges in the interval $2 \leqslant z \leqslant 10$, which yielded 924 interactions, shows that the experimental data are consistent with a decrease in the mean path of the fragments over the first few centimeters of the path which they travel from their production point. The corresponding effect is not found for primary ^{12}C or ^{22}Ne ions.

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Friedlander *et al.*[1] and Jain and Das[2] studied the interaction of the nuclei of a photographic emulsion with ^{56}Fe, ^{40}Ar, and ^{16}O ions at a momentum ~ 2 GeV/c per nucleon and reported observing a decrease in the mean free path $\bar{\lambda}_z$ of the emitted product fragments over the first few centimeters of the path (x) which they traveled away from their production point. The effect was observed for fragments with charges in the range $3 \leqslant z \leqslant 26$ but not for $z = 2$ (Ref. 3). Jain and Das[2] also state that there is no effect at the lower momentum of ~ 1 GeV/c per nucleon.

These results struck a responsive chord. Several theoretical models were proposed to explain the effect; new experiments with photographic emulsions and also by other methods are being carried out; and even further experiments are being planned. In discussing these studies, several physicists have expressed doubt regarding the reliability of the results; these results may be incorrect because of the particular difficulties of the emulsion method and the particular nature of the mathematical analysis.

In the present study we have attempted to avoid these difficulties by simplifying to the maximum extent possible the procedure for obtaining and analyzing the results and by removing the "impurities" represented by possible spurious effects.

We used two stacks of emulsions bombarded by ^{12}C and ^{22}Ne ions, respectively, at 4.1 GeV/c per nucleon in the High-Energy Laboratory at the Joint Institute for Nuclear Research.

Here are the basic principles embodied in the analysis of the experimental data.

1. At this stage of the research we focused on a narrowly defined problem: We attempted to find an answer to the question of whether there is an "integral"effect (without a separation of the fragments on the basis of charge beyond the visual separation of the fragments with $z = 2$). This approach increases the size of the statistical base and eliminates the possibility of an additional error due to the complicated and ambiguous procedure of determining the fragment charge and of correcting the range to refer to a unit charge. Furthermore, an integrated processing of the tracks of the fragments of all charges cannot introduce a spurious amplification of the effect.[1] If the effect does occur (does not occur) for all charges, then it will be seen (will not be seen) in an integrated processing. If, on the other hand, the effect occurs only for certain charges, then it can only be reduced in magnitude by the integrated processing.

2. The primary interactions were sought by the "along the track" method (rather than by the "over the area" method) at high magnification, 60 × 1.5 × 15. This approach ruled out the possibility of missing any poorly defined stars (white stars, for example).

3. As a check for the absence of a spurious effect on the tracks of the ^{12}C and ^{22}Ne primary ions, these tracks were examined at the same distance, 7 cm, in all cases (or they were examined before the interaction), with the transitions to adjacent layers where necessary.

4. From the set of fragments we selected those which were emitted into a narrow forward cone with a vertex angle of 0.1 rad. All the primary fragments which satisfied the emission-angle condition automatically had a potential range $x \geqslant 10$ cm.

5. Fragments of succeeding generations were examined only if their potential range satisfied $x \geqslant 10$ cm.

6. The fragment tracks were examined at the same magnification, 60 × 1.5 × 15, up to $x = 10$ cm (or before the interaction), with transitions to adjacent layers.

7. Part of the film was subjected to a crosscross examination for both the primary ions and the fragments.

The mean free path before an interaction was calculated from the following expression for various distances x from the fragment production point (or before the primary ion entered the plate):

$$\bar{\lambda}(x) = \frac{L(x)}{N_{\mathrm{st}}(x)} = \frac{\sum\limits_{i=1}^{N_{\mathrm{st}}(x)} l_i + N_{\mathrm{trav}}\,\Delta x}{N_{\mathrm{st}}(x)}\,.$$

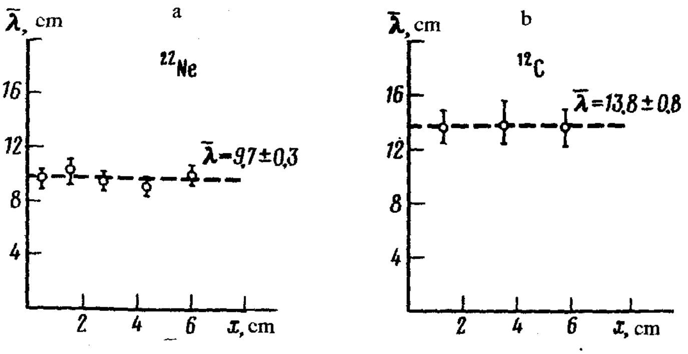

FIG. 1. Mean free path $\bar{\lambda}$ vs the distance traversed, x. a—Primary ^{22}Ne ions (1659 tracks, 853 interactions); b—primary ^{12}C ions (724 tracks, 289 interactions).

Here L is the total length of all the tracks detected on the given path segment Δx near x,$N_{\text{st}}(x)$ is the number of stars on these tracks, l_i is the interaction mean free path within the given path segment ($l_i \leqslant \Delta x$), and $N_{\text{trav}}(x)$ is the number of fragments (or ions) which traverse the distance Δx without interacting.

Figures 1a and b show the results calculated for $\bar{\lambda}(x)$ for 1659 primary ^{22}Ne ions, which produced 853 stars, and for 724 primary ^{12}C ions, which produced 289 interactions. We see that there is absolutely no systematic deviation of the values of $\bar{\lambda}(x)$ from the mean: There is no spurious effect. From the data we calculated the interaction mean free paths for the ^{22}Ne and ^{12}C ions at the momentum of 4.1 GeV/c per nucleon:

$$\bar{\lambda}(^{12}\text{C}) = 13.8 \pm 0.8\,\text{cm}; \quad \bar{\lambda}(^{22}\text{Ne}) = 9.7 \pm 0.3\,\text{cm}.$$

(Here and below, the indicated errors are purely statistical.)

Figure 2 shows results calculated for $\bar{\lambda}(x)$ for the fragments and for the stars that they produce, detected in emulsions bombarded with ^{12}C ions (Fig. 2a) and ^{22}Ne ions (Fig. 2b). Figure 2c shows results for the combined statistical base, which consists of 2034 fragments and 924 interactions. The dashed lines in the figures are the calculated curves for $\bar{\lambda}_H(x)$ corresponding to the absence of the effect in question. These curves were calculated under the assumption that the fragments with charges $z \geqslant 3$ are distributed uniformly in charge.[2)] We found the ratio of the numbers of fragments with $z = 2$ and $z \geqslant 3$ (60% and 72% for ^{22}Ne and ^{12}C, respectively), and we found the mean free path of the $z = 2$ fragments: $\lambda_2 = 20.4 \pm 1.1$ cm. The mean free paths of fragments of charge z were found by interpolating between the experimental values for $z = 2$, $z = 6$, and $z = 10$.

The solid curves show calculations from a model in which the fragments include a small fraction of "anomalons," f, with a short mean free path, $\lambda_a \ll \bar{\lambda}_H$. The other fragments ("normal" fragments) have a range $\bar{\lambda}H$, which was determined in the course of the calculations. The values of f and λ_a were treated as adjusatable parameters and were determined by fitting the experimental points. For all three sets of points we found similar results: Calculations from a model with anomalons have a confidence level $CL \gtrsim 40\%$ at values $f \sim 5\%$ and $\lambda_a \sim 2 \pm 1$ cm, while for the dashed curves the

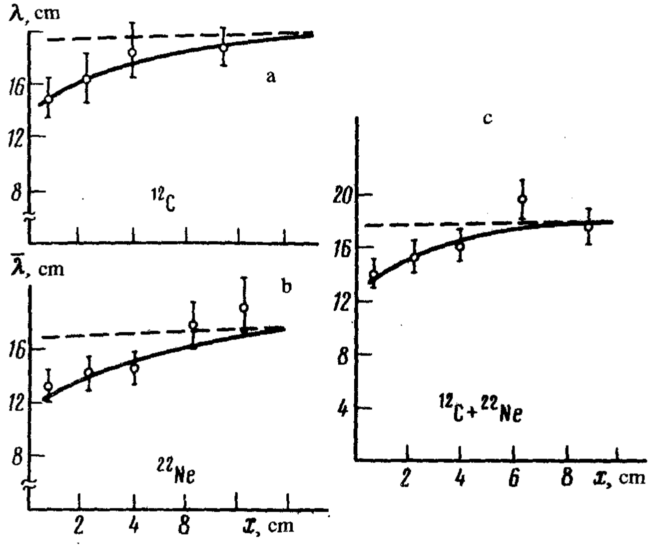

FIG. 2. Values of $\bar{\lambda}(x)$ for fragments produced in the interactions of ^{12}C and ^{22}Ne ions with the nuclei of photographic emulsions. a—^{12}C (945 fragments, 412 stars). The curves were calculated for the parameter values $\bar{\lambda}_H = 19.5$ cm, $\lambda_a = 2.6 \pm 1.9$ cm, and $f = 0.05 \pm 0.03$ (see the text proper for an explanation); b—^{22}Ne (1089 fragments, 512 stars), $\bar{\lambda}_H = 17.5$ cm, $\lambda_a = 2.3 \pm 1.3$ cm, $f = 0.06 \pm 0.03$; c—$^{12}C + ^{22}Ne$ (2034 fragments, 924 stars), $\bar{\lambda}_H = 18.0$ cm, $\lambda_a = 2.0 \pm 1.0$ cm, $f = 0.05 \pm 0.02$.

values of *CL* are on the order of a few tenths of 1%. An attempt to describe the calculated curve in Fig. 2c by the method of least squares, with $\bar{\lambda}_H$ as an adjustable parameter, leads to a confidence level ~3%. For both ^{12}C and ^{22}Ne we find a value of 1.2 for the ratio $k = \bar{\lambda}(x > 3 \text{ cm}/\bar{\lambda}(x < 3 \text{ cm})$. For the complete statistical base we find $\bar{\lambda}(x < 3 \text{ cm}) = 14.7 \pm 0.8$ cm, $\bar{\lambda}(x > 3 \text{ cm}) = 17.8 \pm 0.8$ cm, and $k = 1.21 \pm 0.11$.

All the fragments were examined to find fragments with $z = 2$ and $z \geqslant 3$. The separation was made visually, so that the group with $z = 2$ may contain some admixture of fragments with a higher charge. Analyzing the data, we see a trend toward an intensification of the effect for the group with $z \geqslant 3$. The best description ($CL = 70\%$) is found with $f = 0.12 \pm 0.04$ and $\lambda_a = 2.9 \pm 1.4$ cm.

In summary, this set of data on fragments produced in the interactins of ^{12}C ions and in the interactions of ^{22}Ne ions, at a momentum of 4.1 GeV/c per nucleon, is consistent with the existence of an effect. This study must be pursued to finally resolve the question of whether the effect exists and to analyze it in detail.

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[1] The trivial (an small) spurious effect which results from the different rates at which the fragments with different values of z "die off" was taken into account (see the discussion further on).

[2)] The use of a dome-shaped distribution instead of a uniform distribution, by analogy with Refs. 2 and 4, has essentially no effect on the results.

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[3] P. L. Jain *et al.*, Phys. Rev. **C25**, 3216 (1982).
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