Anomalons at a momentum of 4.1 GeV/*c* per nucleon

A. A. Kartamyshev, K. N. Mukhin, E. V. Nilov, O. O. Patarakin,
M. M. Sulkovskaya, A. F. Sustavov, and L. A. Chernyshova
I. V. Kurchatov Institute of Atomic Energy, Moscow

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Analysis of 4138 fragments with a charge $2 \leqslant Z \leqslant 10$, which yield 1881 interactions, shows that the mean free path of the fragments decreases over the first few centimeters from the production point. The fragments were produced in the interaction of ^{12}C and ^{22}Ne ions with a momentum of 4.1 GeV/c per nucleon with emulsion nuclei. This effect is seen both for fragments with $Z = 2$ and for fragments with $3 \leqslant Z \leqslant 10$. There is no corresponding effect for the primary ^{12}C and ^{22}Ne ions.

The 1980 publication of experiments[1] carried out on the Bevelac accelerator provoked a serious discussion in the scientific community of the possible existence of "anomalons": relativistic projectile fragments with an anomalously short mean free path λ_a over the first few centimeters of their travel away from their production point. Earlier evidence for the existence of such entities had been found in the 1960s in cosmic-ray experiments (see Refs. 2–4, for example), but a detailed study of this effect was not possible until recently, when intense beams of large-Z ions with energies of several GeV/N became available. More than 15 studies have now been carried out. Effective use is being made of several methods other than the emulsion method: a bubble chamber,[5] a plastic detector,[6,16] and an electronic method.[7] The situation remains quite uncertain, however: Some studies[1,5,6,8–12] find an effect, while others[7,13] do not. A comparison reveals that the various methods are not perfect: In the bubble chambers, the first few centimeters of the path are difficult to see; the plastic detectors and the electronic method detect only fragments with large Z and contain only light target nuclei; etc. The emulsion method still seems to be the best method, and it is on this method that hopes for resolving the possible existence of anomalons are pinned.

This letter reports an effort to resolve this question in one laboratory, by the simplest possible emulsion method. The mean free paths of primary ^{12}C and ^{22}Ne ions with a momentum of 4.1 GeV/c per nucleon and of the projectile fragments produced in the interaction of these ions with emulsion nuclei were measured. We took a "fragment" to be an ion that has a charge between $Z = 2$ and the charge of the primary ion, which is moving forward in a cone with a vertex angle $\leqslant 0.1$ rad, and whose velocity is roughly the same as that of the primary ion. The primary tracks were measured to 7 cm from the edge of the plate, where all the fragments had a potential range of 10 cm. In the emulsion method, the charge separation of the fragments usually has an error of ± 1, which could distort the actual mean free path λ as a function of the distance x. To avoid this distortion, we adopted an integral method of processing the fragments of all charges. In this approach, the observed effect could only be reduced (if it exists only for fragments with certain definite values of Z); there is no way the effect could be intensified. The increase in the statistical base achieved by resorting to an integral method improves the reliability of the results. The method is described in detail in Ref. 11.

To check the method, we processed tracks of the primary ^{12}C and ^{22}Ne ions. Figure 1 shows the mean free path λ versus the distance traversed by the ion from the entrance to the plate. The experimental points can be described well by the horizontal lines $\lambda_{\mathrm{Ne}} = 10.5 \pm 0.2$ cm and $\lambda_{\mathrm{C}} = 13.6 \pm 0.5$ cm, with no significant deviations.

Figure 2 shows the entire statistical base for fragments with charges $2 \leqslant Z \leqslant 10$ resulting from the interactions of ^{12}C and ^{22}Ne nuclei with emulsion nuclei (Fig. 2a) and for fragments produced exclusively by the ^{22}Ne nuclei (Fig. 2b). The dashed curves

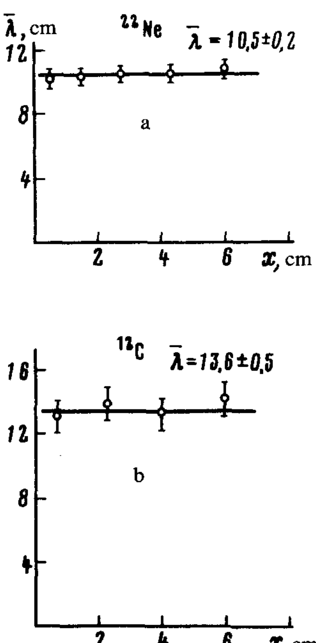

FIG. 1. Mean free path versus the distance traversed, x, for the primary ions. (a) ^{22}Ne (4319 tracks, 2094 interactions); (b) ^{12}C (1898 tracks, 763 interactions).

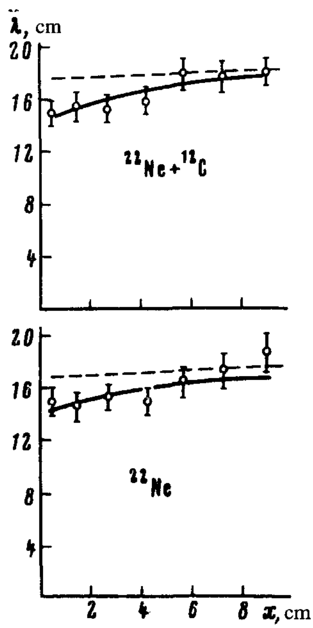

FIG. 2. The dependence $\bar{\lambda}(x)$ for fragments with $2\leqslant Z\leqslant 10$ produced in the interactions of ^{22}Ne and ^{12}C ions with emulsion nuclei. (a) For all fragments (4138 fragments, 1881 interactions); (the solid curve corresponds to $\lambda_a = 3.4 \pm 1.4$ cm, $\lambda_n = 18.0$ cm, $f = 5.8 \pm 1.9\%$ and has a confidence level CL = 75%); (b) for fragments from ^{22}Ne ions (2959 fragments, 1369 interactions) (the solid curve corresponds to $\lambda_a = 3.0 \pm 1.8$ cm, $\lambda_n = 17.0$ cm, $f = 4.5 \pm 2.1\%$ and has a confidence level CL = 60%).

were calculated under the assumption that there is no effect and with allowance for the decrease in the relative number of large-Z fragments with distance. We see that the description is unsatisfactory (the confidence level is CL = 6×10^{-4} for the entire statistical base and CL = 10^{-2} for the fragments produced by the ^{22}Ne ions). The solid curve shows results calculated from a model in which there is a small fraction (f) of anomalons with $\lambda_a \ll \lambda_n$ among the fragments. The rest of the fragments have the normal mean free path λ_n, which was held constant in the calculations. The best description (CL = 75% and CL = 60% for Figs. 2a and 2b, respectively) was obtained with the values $f\sim 5\%$ and $\lambda_a \sim 3$ cm. Calculations based on an alternative model, in which all the fragments are anomalous and revert to a normal state in a time τ, yield $\tau = 3.7\times 10^{-11}$ s and an anomalon interaction cross section 1.5 times the normal cross section. The parameters found for the effect are approximately the same as those from Refs. 1, 6, 8, and 10, found for a momentum of 2 GeV/c per nucleon. This agreement may be advanced as an argument against the decay model.

Crucial to the identification of a correct theoretical model is whether the effect occurs at small values of Z. The data from the old cosmic-ray experiments imply an effect for[4] $Z = 1,2$, and 3; more recently, the effect has been observed[14] for $Z = 2$ at a momentum of 2.1 GeV/c per nucleon. In Ref. 15, in contrast, the effect was not detected for $Z = 2$. Fragments with $Z = 2$ were not studied in the other experiments.

Since the ionizing capacities of fragments with $Z = 2$ and $Z\geqslant 3$ differ by a factor

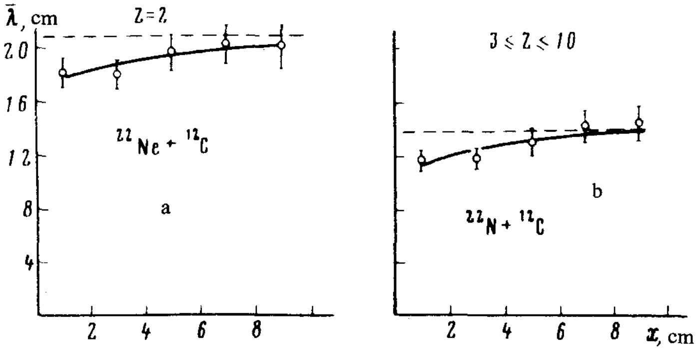

FIG. 3. Comparison of $\bar{\lambda}(x)$ for fragments with various values of Z. (a) Fragments with $Z=2$ (2626 fragments, 1065 interactions). Solid curve—$\lambda_a = 4.2 \pm 2.9$ cm, $\lambda_n = 21.0$ cm, $f = 4.9 \pm 2.8\%$, CL $\approx 100\%$; dashed curve—no effect, CL $\approx 3\%$. (b) Fragments with $3 \leqslant Z \leqslant 10$ (1512 fragments, 816 interactions). Solid curve—$\lambda_a = 3.0 \pm 1.6$ cm, $\lambda_n = 14$ cm, $f = 8.0 \pm 3.5\%$, CL $\approx 100\%$; dashed curve—CL $\approx 2\%$.

of more than two, such fragments can easily be identified. Figure 3a shows fragments with $Z=2$ from our complete statistical base, while Fig. 3b shows fragments with $3 \leqslant Z \leqslant 10$. We see that the anomalous behavior of λ is found in both groups of fragments. Comparison of the results found for the parameters f and λ_a (see the Fig. 3 caption) suggests that the effect is slightly stronger for the group with $Z \geqslant 3$.

Let us summarize the results of this study. 1) We have observed a decrease in the mean free path over the first few centimeters for projectile fragments resulting from the interactions of ^{12}C and ^{22}Ne ions at a momentum of 4.1 GeV/c per nucleon. 2) This effect is observed both for fragments with $Z=2$ and for fragments with $Z \geqslant 3$.

[1]E. M. Friedlander *et al.*, Phys. Rev. Lett. **45**, 1084 (1980).
[2]A. Milone, Nuovo Cim. Suppl. **12**, 353 (1954).
[3]E. M. Friedlander and M. Spirchez, Nucl. Sci. Abstr. **15**, 3457 (1961).
[4]B. Judek, Can. J. Phys. **46**, 343 (1968); **50**, 2082 (1972).
[5]G. N. Agakishiev *et al.*, Preprint R1-81-79, Joint Institute for Nuclear Research, Dubna, 1981; Preprint R1-82-795, 1982.
[6]M. L. Tinckness, P. B. Price, and S. Perlmutter, Phys. Rev. Lett. **51**, 1948 (1983).
[7]J. D. Stevenson *et al.*, Phys. Rev. Lett. **52**, 515 (1984).
[8]P. L. Jain *et al.*, Phys. Rev. Lett. **48**, 305 (1982).
[9]H. B. Barber, P. S. Freier, and C. J. Waddington, Phys. Rev. Lett. **48**, 856 (1982).
[10]E. M. Friedlander *et al.*, Phys. Rev. C **27**, 1490 (1983).
[11]E. A. Alekseeva *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **38**, 411 (1983) [JETP Lett. **38**, 500 (1983)].
[12]M. M. Aggarwal *et al.*, Phys. Lett. B **112**, 31 (1982).
[13]B. P. Bannik *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **39**, 184 (1984) [JETP Lett. **39**, 219 (1984)].
[14]E. M. Friedlander *et al.*, LBL Report No. 12652, 1981, 416.
[15]A. Z. M. Ismail *et al.*, Phys. Rev. Lett. **52**, 1280 (1984).
[16]W. Heinrich *et al.*, Phys. Rev. Lett. **52**, 1401 (1984).

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