Certain aspects of the transverse-momentum distribution of fragments of relativistic ^{6}Li nuclei in a nuclear emulsion

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A study has been made of the ratio of (a) the mean value of the observed transverse momenta of the fragments of the ^{6}Li nucleus, with a momentum of 4.5 GeV/c per nucleon, in the interaction of this nucleus with emulsion nuclei to (b) the mean value of the transverse momenta of the fragments in the c.m. frame of the two fragments. It was found that this ratio does not differ from the value ($\approx \sqrt{2}$) expected for the case of an independent emission of fragments. The size of the region in which the doubly charged fragments of ^{6}Li are produced is about half the size of the region in which the fragment protons are produced. The Fermi momentum of the ^{6}Li nucleus for protons is 111 ± 6 MeV/c. Evidence for the observation of an exchange of nucleons between the relativistic nucleus and the target is found. The corresponding cross section is $\sigma_{ex} = 12 \pm 6$ mb.

1. It was shown in Ref. 1 that the value of $\eta = \langle P_\perp \text{(lab)}\rangle / \langle P_\perp^* (1-2)\rangle$ for the independent emission of fragments of different masses is approximately equal to $\sqrt{2}$. For fragments of the ^{22}Ne nucleus with a momentum of 4.1A GeV/c, a value of η significantly different from $\sqrt{2}$ was found. This result prompted the suggestion that excited prefragments exist in the fragmentation of relativistic ^{22}Ne nuclei.

In this letter we are reporting preliminary results of an analysis of fragments of the ^{6}Li nucleus with a momentum of 4.5 GeV/c per nucleon in an inelastic interaction with nuclei in a nuclear emulsion. The experimental conditions resulted in an impressive sample of 473 events containing singly and doubly charged fragments of the primary ^{6}Li nucleus. For each fragment we measured its charge Z, the angles ϕ and α in the XY and XZ planes with $\bar{P}_0$ directed along the X axis, and the angles θ_{12} (θ_{23},θ_{13}) for events containing two and three fragments. The fragment momentum P (or, more precisely, the quantity $p\beta c$) and its error were estimated from measurements of multiple scattering over the maximum possible track length of a fragment in the emulsion chamber (up to 10 cm). All measurements were carried out on an MPÉ-11 microscope with a stage for multiple scattering with fluoroplastic guides. This microscope was equipped with detectors of the coordinates along the X, Y, and Z axes; upon an instruction from the user, the readings of these detectors were sent to a personal computer for processing.

2. All the results of the present study are based on an individual separation (classification) of each fragment, initially with respect to Z and then with respect to

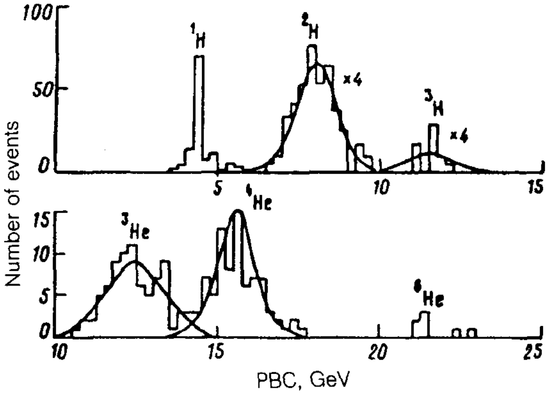

FIG. 1. Separation of the isotopes of hydrogen (at the top) and of helium on the basis of measurements of $p\beta c$. Histogram—Experimental; smooth curves—normal distributions found by the least-squares method.

the mass number A. This classification is based on physical considerations. The basic idea of the classification,[2] according to which a given observation of a particle momentum P should be assigned to that general set in which it is most plausible, is realized in our case through a determination of A from the minimum of the quantity

$$t = \mathrm{mod}[P - P_0 \cdot A]/\Delta P, \tag{1}$$

where A takes on the values 1, 2, 3 ($Z=1$) or 3, 4, 6 ($Z=2$), and P_0 is the momentum per nucleon of the ^{6}Li nucleus. For any distribution of estimates of P around its actual value, the probability for having a given A is larger, the closer the measured value of P (in units of ΔP) is to the given nominal $P_0 \cdot A$. The weight of a given measurement, which is proportional to the density of the normal distribution with the mean value $P_0 \cdot A$ and the variance $(\Delta P)^2$, was used in plotting histograms (Fig. 1).

The mean weighted values of $\langle P \rangle_A$ for each A show that the measurements of P and the classification are totally reliable. For hydrogen and deuterium, for example, these values are 4.3 ± 0.6 and 8.2 ± 0.7, while for helium-3, -4, and -6 the values are 12.9 ± 1.3, 16.9 ± 1.5, and 23.6 ± 4.0 GeV/c. The yields of the isotopes ^{1}H and ^{2}H are comparable, as are those of ^{3}He and ^{4}He. During fragmentation of Ni, Ag, Sn, Au, and U nuclei by 1-GeV protons,[3] the yields of the ^{4}He and ^{3}He isotopes differ by a factor from 10 to 40 and depend on the value of N/Z of the bombarded nuclei. Even for ^{58}Ni and ^{112}Sn with $N/Z \simeq 1$, the ^{3}He yield is no more than 10% of the ^{4}He yield. For the fragmentation of relativistic nuclei with $N/Z = 1$ (^{12}C, ^{16}O) we find from Ref. 4 that the yields of these isotopes are comparable, as they are in our experiment. Of the 244 particles with $Z=1$, 22 have $A=3$; among the 192 doubly charged fragments, seven fragments are assigned to ^{6}He.

It can be seen from Fig. 1 that although there are only a few particles with $Z=2$ and $A=6$, it can be regarded as an established fact that the ^{6}He isotope is present in the ^{6}Li fragmentation products. This could happen only as the result of a charge exchange of nucleons of the incident nucleus and the target. However, if that process occurs with the observed cross section, then there should be events involving pickup of a target nucleon, a decay of the ^{6}He into two ^{3}H's, and, finally, an apparent fragmentation of ^{6}Be (^{7}Be) into two helium isotopes. The latter possibility looks particularly

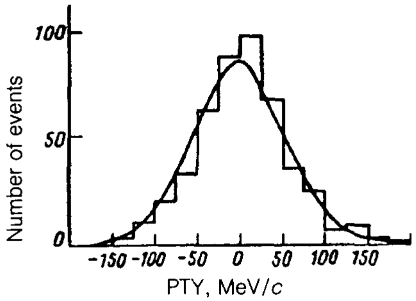

FIG. 2. Distribution of the projections of the transverse momenta of the protons. The smooth curve is a normal distribution with $\sigma_0 = 54.8$ MeV/c.

interesting, and the identification is particularly reliable. We found one "pure" event of this sort. It does not contain any product relativistic particles, which are primarily π mesons, or slow particles from destruction of the target (primarily protons).

The fraction of events (C_A) for each A at a given Z was found by two other methods. In one case this was the ratio of the sums of the weights of all events with the given A to the sum of the weights of all events with the given Z. In this case, each event in the class of events with the given A enters with a certain probability $W < 1$, while it enters the two other classes with a probability of $1 - W$. In the second case, by plotting a histogram we can describe it for each Z by a mixture of three normal distributions with eight adjustable parameters: C_1, C_2, σ_1, σ_2, σ_3, $\langle P_1 \rangle$, $\langle P_2 \rangle$, and $\langle P_3 \rangle$. Here we minimize the sum of the squares of the deviations of the observed and calculated probabilities for finding events in each channel of the histogram. Both of these methods for statistical separation of isotopes yielded values of C_A for the given Z and A which agree with the individual classification on the basis of the minimum of t. The smooth curves in Fig. 1 are normal distributions describing the histogram for the latter method of finding C_1 and C_2 by the least-squares method.

We found a total of thirteen events, which refer to charge exchange or the pickup of target nucleons according to the measurements of Z and P. Of these, three events were the breakup of an excited ^{6}He into two ^{3}H's, with each fragment having a momentum 12 ± 1 GeV/c. Working from the experimental conditions, we find a cross section $\sigma_{ex} = 12 \pm 3$ mb or $\simeq 1.5\%$ of σ in (^{6}Li+Em).

3. The results of this classification of the ^{6}Li fragments were used to estimate the constant σ_0 in the distribution of their transverse momenta. The distribution of the projections of the transverse momenta of the proton fragments, PTY$= P_0 \cdot \sin\phi$ (Fig. 2), agrees with a normal distribution $N[0,\sigma_0^2]$ with $\sigma_0 = 54.8 \pm 2.5$ MeV/c. The transverse momenta themselves thus have a Rayleigh distribution.

The value found for σ_0 for protons in this experiment is significantly smaller than the value expected (76 MeV/c) on the basis of the Fermi momentum.[5] In our experiment, however, σ_0 is an observable, while P_F in Ref. 5 is one of the adjustable parameters of the model. According to our data, the Fermi momentum of the ^{6}Li nucleus for protons is 111 ± 6 MeV/c.

The distribution of the projections of the transverse momentum, PTY, for particles with $Z=2$ also agrees with a normal distribution, but with $\sigma_{0\alpha} = 137.4 \pm 8.7$

MeV/c. The expected value of this quantity is $\simeq 71$ MeV/c, where we are taking the mass of the α particle into account. The value observed experimentally for $\sigma_{0\alpha}$ is thus about twice as large. Using the uncertainty principle with an equals sign,[6] we thus have $\langle P_\perp \rangle \langle R_{FR} \rangle = \hbar/2$, where $\langle R_{FR} \rangle$ is the typical size of the fragmentation region. We thus find $\langle R_{FR} \rangle_p / \langle R_{FR} \rangle_\alpha \simeq 2$. The size of the region in ^{6}Li, from which protons undergo fragmentation as this nucleus interacts with an emulsion nucleus, is roughly twice the size of the region from which α particles undergo fragmentation.

In events with two and three fragments, we find $P_\perp^*$, the transverse momentum of the fragments in their c.m. frame, from the invariant mass of the two particles.[1] Here we use the angle (measured directly) between the two tracks of the fragments, θ_{12}. The errors in the estimate of this angle on the basis of the angles ϕ and α of the two particles turn out to be approximately twice that found from a direct measurement.

A result found in this study for all pairs of fragments, for proton–proton pairs, and for proton–α pairs is that we do not see a deviation of η from $\sqrt{2}$ outside the errors. The value of the ratio η was also found by the Monte Carlo method (as in Ref. 1) with a statistical base ten times that of the experiment. For all events we thus have $\eta = 1.36 \pm 0.05$ experimentally, and $\eta = 1.39 \pm 0.02$ according to the Monte Carlo method.

In summary, fragmentation of relativistic ^{6}Li nuclei does not have the stage of a formation of prefragments. The fragments which are observed are produced directly from the ^{6}Li nucleus.

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