Fragmentation of $^7\text{Li}$ Relativistic Nuclei on a Proton into the $^3\text{H} + ^4\text{He}$ Channel

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Abstract—In a track nuclear photoemulsion exposed to a beam of $^7\text{Li}$ nuclei accelerated to a momentum of 3 GeV/c per nucleon on the synchrophasotron of the Joint Institute for Nuclear Research (JINR, Dubna), 13 events in which $^7\text{Li}$ nuclei interacting with protons break up into $^3\text{H}$ and $^4\text{He}$ fragments were detected among 3730 inelastic-interaction events. For this fragmentation channel, the cross section was found to be $8 \pm 2$ mb. The average value of the fragment total transverse momentum was $214 \pm 5$ MeV/c. This value exceeds markedly the average value of the transverse-momentum transfer in the coherent dissociation of $^7\text{Li}$ nuclei on track-emulsion nuclei ($166 \pm 5$ MeV/c). The recoil–proton transverse momentum was on average 98% of the total proton momentum. The longitudinal-momentum distribution of protons was characterized by a variance of 16 MeV/c and a mean value of 37 $\pm$ 2 MeV/c.

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INTRODUCTION

Inelastic interactions of nucleons or nuclei with nuclei at high energies (corresponding to momenta of a few GeV/c units per nucleon) for the case where one reaction channel is singled out have been studied much less adequately than elastic scattering. The theory of inelastic reactions at these energies is based on various versions of the Coulomb mechanism of the excitation of nuclei [1] and on the Glauber–Sitenko diffraction theory of multiple collisions [2]. In practical applications, all of these approaches employ various approximations and therefore call for an experimental verification. In the overwhelming majority of studies devoted to considering inelastic collisions, the deuteron, which is the simplest nucleus, is used as a probing nucleus incident to the target. However, the presence of a neutron in the final state and the uncertainty in the states of the target nucleus after a collision event complicate experimental verification of the aforementioned theoretical approaches.

Among inelastic interactions of $^7\text{Li}$ nuclei in a track nuclear emulsion that were accelerated to a momentum of 3 GeV/c per nucleon, events of the cluster fragmentation of $^7\text{Li}$ nuclei into the $^3\text{H} + ^4\text{He}$ channel without meson production and without apparent excitation of target nuclei, this being indicative of a coherent fragmentation of projectile nuclei, were detected in [3, 4]. The vector sum of the transverse momenta of relativistic fragments that was measured experimentally in those events is the transverse-momentum transfer in the respective reaction, $Q$. The measured dependence of the differential cross section on the momentum transfer $Q$ was analyzed in [4] under the assumption of the two-cluster structure ($^3\text{H} + ^4\text{He}$) of the $^7\text{Li}$ nucleus [5, 6] and on the basis of the formalism of Glauber–Sitenko theory for the case of involvement of nuclear clusters [7]. This analysis made it possible to reveal that this dependence of the differential cross sections with respect to $Q$ was different in form in inelastic and elastic diffraction processes and resulted in drawing conclusions on the role of electromagnetic and nuclear interactions and in pinpointing facets of interest for their further study, which included the Coulomb peak region standing out at small $Q$ and investigation of commensurate diffraction-cross-section oscillations predicted for inelastic processes on pure target nuclei. Experimental data on the fragmentation of relativistic nuclei on a proton target may serve as an important test of the theoretical model used to describe the two-cluster fragmentation of light nuclei, as well as a test of the method used to identify the channels under study.

In the present article, which reports on our investigations pursuing further those described in [3, 4], we give an account of the result of searches for and
The emulsion chamber was exposed to a beam of $^7$Li, which entered the emulsion chamber from its endface and for nuclear research (JINR, Dubna). During irradiation, the nuclei accelerated to a momentum of 3 GeV/c involving the fragmentation of relativistic nuclei. Tracks of $^7$Li relativistic nuclei could be traced with a microscope from the locus where $^7$Li nuclei entered a track-emulsion layer either to an event of nucleus-nucleus interaction or to their escape from the track-emulsion layer. The total length of all traced tracks, $L$, was used to determine the mean range of the nuclei and the reaction cross section. The charges of relativistic fragments of $^7$Li nuclei were determined visually by their track-ionization density, which differed by a factor of about four for singly and doubly charged particles. The direction of the relativistic-nucleus track was determined from the coordinates of interaction vertex and the coordinates measured for several points on the track over a length of up to 2 mm from the interaction vertex. The direction of motion of a relativistic fragment was determined from the coordinates of the interaction vertex and the coordinates measured for the points on the track at distances of 500 and 1000 $\mu$m from the interaction vertex. For the results of the measurements, we took values averaged over several measurements. In some individual measurements, the scatter of the fragment polar angle $\theta$ about the primary direction of motion of the $^7$Li nucleus was about 0.03°, while the scatter of values of the azimuthal angle $\psi$ in the plane orthogonal to the direction of motion of the $^7$Li nucleus was about 3°. The mass of a relativistic fragment was determined by the method of measurement of multiple Coulomb scattering of the fragment in the track emulsion in the horizontal plane. In order to determine the average particle-scattering angle, the $Y$ coordinates of the track being considered were measured consecutively along the track at a distance $l$ between the points by using an MPE11 measuring microscope. The second differences of the $Y$ coordinates, $D$, characterize consecutive deflections of the track in the horizontal plane, while the ratio $D/l$ characterizes the scattering angle over the length $l$. In the case of the multiple Coulomb scattering of a charged particle, scattering angles and second differences of $Y$ coordinates obey a normal distribution, while the average value $\langle |D| \rangle$ over a cell of length $l$ has the form $\langle |D| \rangle = KZf^{3/2}/(p\beta c)$, where $Z$, $p$, and $\beta c$ are the particle charge, momentum, and velocity, respectively. For a track emulsion of the BR-2 type, use is usually made of the experimentally determined scattering constant, which is equal to $K = 28.5$. The values of $D$ and $l$ are given in $\mu$m units, while the value of $(p\beta c)$ is measured in GeV units. This relation between the measurable quantity $|D|$ and quantity $(p\beta c)$ makes it possible to estimate particle momenta and to perform a mass separation of fragments having the same charge. At the nucleon momentum of 3 GeV/c, the value of $\beta$ is close to unity, so that the distribution of particles with respect to $(p\beta c)$ reflects the momentum distribution almost completely. The

**EXPERIMENTAL PROCEDURE**

In a BR-2 track nuclear photoemulsion, there are $2.97 \times 10^{22}$ hydrogen atoms per 1 cm$^3$. In the track emulsion irradiated with $^7$Li relativistic nuclei, projectile-nucleus fragmentation on free protons must therefore also be observed in addition to nucleus-nucleus collisions. Processes involving the fragmentation of light nuclei on a proton target in a track nuclear photoemulsion are also being studied by the BECQUEREL Collaboration [8]. A recoil proton must be observed in the interaction of a projectile nucleus with a proton. It is common practice to assume that, at the vertex of nucleus-nucleus interaction in a track emulsion, a recoil nucleus may be reliably detected if its range exceeds 2 $\mu$m. The momentum of a proton is about 20 MeV/c if its range is 2 $\mu$m and about 30 MeV/c if its range is 5 $\mu$m. Such a low energy threshold for proton detection makes it possible to study the fragmentation process in a track emulsion on a proton target over the entire momentum-transfer range, including the region of low momenta. For the sake of comparison, we note that, in studying the dissociation of a $^{12}$C nucleus to three alpha particles on a proton target in a propane bubble chamber [9], recoil protons were detected only if their momenta exceeded 150 MeV/c. Investigation of an inelastic process on a proton target in a track emulsion is also of interest from the methodological point of view. In measuring the range in a track emulsion and in determining the momentum of the target nucleus in the final state, one knows the transverse momenta of all particles, including relativistic fragments and the target nucleus. The reconstruction of interaction kinematics makes it possible to test the reliability of fragmentation-channel identification and the validity of the procedure used to analyze processes involving the fragmentation of relativistic nuclei.

In the present experiment, use was made of an emulsion chamber formed by layers of a BR-2 track nuclear photoemulsion, which is sensitive to the minimum ionization of singly charged particles. Emulsion layers had a thickness of about 600 $\mu$m, and their linear cross-sectional dimensions were $10 \times 20$ cm$^2$. The emulsion chamber was exposed to a beam of $^7$Li nuclei accelerated to a momentum of 3 GeV/c per nucleon at the synchrophasotron of the Joint Institute for Nuclear Research (JINR, Dubna). During irradiation, the track-emulsion layers were arranged to be parallel to the beam axis, so that beam particles entered the emulsion chamber from its endface and traversed the emulsion layers along their long sides.