Deep inelastic interactions of fast protons with Ar^{40} nuclei

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The yield cross sections, the average multiplicities and the angular anisotropy for the secondary particles in the interaction of protons with Ar^{40} nuclei at 1 GeV are determined. The angular and energy spectra and the dependence of the yield of the given type of particles on the disintegration multiplicity are obtained for the reaction products.

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The deep inelastic nuclear disintegrations by fast particles are studied intensively in a number of laboratories (see, for example, review articles 1 and 2). However, the heretofore available experimental data on such processes were obtained either for a complex nuclear target (photographic emulsion studies) or in the inclusive experiments. Any part of the energy or angular distribution of one of the reaction products can always be described satisfactorily by varying the theoretical parameters. Therefore, to verify the reliability and generality of the theoretical analysis and to further refine it, it is necessary to record in one experiment the yields of the different reaction products in a wide energy and angular range and to correlate them. Of course, an unambiguous analysis requires that the experiment be carried out using pure nuclear targets.

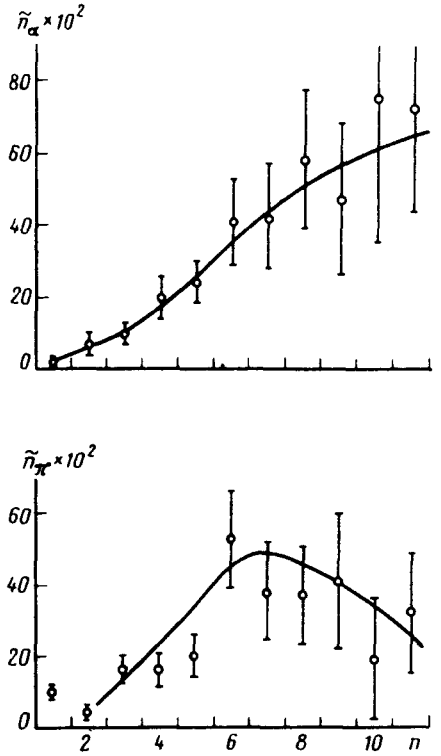

FIG. 1. Dependence of the relative yield of $\pi^{\pm}$ and α on the multiplicity (the curves are for guiding the eye).

The disintegrations of Ar^{40} nuclei were studied by using a hybrid gas-liquid chamber.[3] The experimental setup and the data-evaluation technique are described in Refs. 4 and 5. It was determined that the total inelastic cross section for interaction of 1-GeV protons with Ar^{40} nucleus is $\sigma_{in} = 660 \pm 40$ mb (the error is statistical). The average multiplicity of the charged particles in the disintegration is $n = 4.2 \pm 0.3$.

The charged products of interaction can be divided into three groups: proton group, helium group, and meson group. The cross sections of the particle yield, the average multiplicities and the "forward-backward" ratios were determined for each group. These data are given in Table I together with the results of the calculation in terms of the modified intranuclear cascade (MIC)[7] The tracks of the proton group comprise the largest part ($\sim 85\%$) of the secondary particles. The π^+ mesons could be distinguished from the π^- mesons because of the presence of the magnetic field. The ratio of the cross sections for the yield of these particles was $\sigma(\pi^+)/\sigma(\pi^-) = 3.5 \pm 1.0$. The calculation according to the MIC gives a much smaller value for this ratio: 2.3 ± 0.4.

By using the described experimental technique, we were able to measure the production cross sections of one, two, etc. particles of specific type. The results for π mesons and for α particles are given in Table II.

The following conclusions may be drawn from the examined angular and energy

TABLE I. Yield Cross Sections (σ), Average Multiplicities (n), and "Forward-Backward" (F/B) Ratios for Different Kinds of Particles.

Particle		σ, mb	$\bar{n}$	F/B
H	exp.	2360 ± 110	3.6 ± 0.2	2.2 ± 0.2
	MIC	2500 ± 100	4.0 ± 0.2	2.7 ± 0.1
He	exp	160 ± 40	0.24 ± 0.07	1.5 ± 0.3
	MIC	230 ± 25	0.37 ± 0.04	1.6 ± 0.2
π^-	exp.	34 ± 5	0.05 ± 0.01	1.5 ± 0.2
	MIC	64 ± 10	0.10 ± 0.02	2.1 ± 0.2
π^+	exp.	121 ± 30	0.18 ± 0.04	2.4 ± 0.4
	MIC	150 ± 10	0.24 ± 0.02	2.5 ± 0.2
$\pi^\pm$	exp	155 ± 30	0.23 ± 0.04	2.2 ± 0.4
	MIC	214 ± 14	0.34 ± 0.03	2.4 ± 0.2

distributions of the secondary particles. The energy spectrum for the particles of the proton group indicates that the reaction produces mainly particles which leave the so-called "black" tracks-protons with energies up to 30 MeV. On the average, only 1.1 particles per interaction have an energy >30 MeV. The MIC describes satisfactorily both the energy and the angular distributions of the particles of this group. The energy spectrum of the particles of helium group is mainly evaporative, although approximately 15% of the particles have an energy more than double that of the nominal Coulomb barrier (>15 MeV). In spite of the fact that the experimental value of F/B coincides with the calculated value for the α group (see Table I), the character of the observed angular distribution differs noticeably from the given MIC: in the experiment we observed for the back hemisphere a large isotropy of the yield of the helium nuclei compared to the helium nuclei emitted to the front hemisphere. More than half of the charged π mesons ($\sim 60\%$) have an energy <100 MeV. The energy spectrum and the angular distribution of pions are described in terms of the MIC not as well as similar dependences for the particles of the proton group.

An analysis of the relative yield of the particles of the helium and pion groups as a function of the multiplicity of the tracks in the disintegration revealed a correlation-the relative yield of π and α increases with increasing multiplicity. (The relative yield

TABLE II. Cross Sections for Multiple Production of π Mesons and α Particles.

Particle \ Process	σ_1	σ_2	σ_3
	mb	mb	mb
He	110 ± 40	20 ± 10	3 ± 2
π	120 ± 25	17 ± 8	1

is defined as the ratio of the number of specific particles in the disintegrations of a given multiplicity to the total number of interactions of this multiplicity.) These dependences, are given in Fig. 1. One can see that the character of these dependences is different: if the yield of the α particles increases with increasing multiplicity of the disintegration, then the yield of the π mesons can have a maximum at $n = 6$–7. It should be noted that Lock *et al.*,[8] who studied the disintegration of photographic emulsion nuclei by 950-MeV protons, indicated that the stars with more than nine charged particles have no charged π mesons.

Thus, we obtained for the first time the experimental data on the disintegration of Ar^{40} nuclei by 1-GeV protons. The results demonstrate that the new track apparatus-the hybrid gas-liquid chamber—can be used extensively for systematic studies of many—particle hadron-nuclear interactions in pure targets. The evaluation of the experimental data is continuing.

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[1]Yadernye vzaimodeĭstviya v zashchite kosmicheskikh korableĭ (Nuclear Interactions in the Shields of Spaceships), edited by N.A. Perfilova and E.E. Kovaleva, Atomizdat, M., 1968.
[2]V.S. Barashenkov and V.D. Toneev, Vzaimodeĭstviya vysokoénergetiches-kikh chastits i atomnykh yader s yadrami (Interaction of High-Energy Particles and Atomic Nuclei with Nuclei), Atomizdat, M., 1972.
[3]L.V. Bakanov *et al.*, NIM **144**, 99 (1977).
[4]L.V. Bakanov, V.E. Bunakov, K.N. Ermakov, V.D. Lebedev, V.V. Miroshkin, N.M. Nesterov, V.V. Pashuk, M.V. Stibnikov, N.A. Tarasov, and M.G. Tverskoĭ, Pis'ma Zh. Eksp. Teor. Fiz. **25**, 337 (1977) [JETP Lett. **25**, 313 (1977)].
[5]Yu.A. Karzhavin *et al.*, Pribory i Tekhnika Eksperimenta (Sov. Instruments and Experimental Techniques) No. 5, 54 (1963).
[6]L.V. Bakanov *et al.*, Preprint LIYaF-440, Leningrad, 1978.
[7]V.E. Bunakov and M.M. Nesterov, Phys. Lett. **60B**, 417 (1976); V.E. Bunakov *et al.*, Phys. Lett. **73B**, 267 (1978).
[8]W.O. Lock *et al.*, Proc. Roy. Soc. **A230**, 215 (1955).