resonance in the pion-nucleon system have been observed.

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Yu. R. Gismatullin and V. I. Ostroumov, *Mechanism of proton emission from nuclei accompanying inelastic scattering of intermediate-energy π^- and K-mesons.* In the first experiments on the investigation of a reaction of the type (π, πN) with the nuclei formed being recorded, it was observed that its excitation function in the region 100–300 MeV largely repeats the resonance dependence of the elastic scattering cross section of π-mesons scattered by free nucleons.[1] This served as a basis for the assertion that inelastic scattering of π-mesons by nuclei accompanied by emission of a single proton or neutron occurs by direct knockout and the deformation of the resonance curve $\sigma(E_\pi)$ is due only to the Fermi motion of nucleons, which scatter the pion. In accordance with this assumption, the cross section for knocking out a nucleon must depend very strongly on the sign of the incident meson in the indicated energy range. However, measurements of the so-called isotopic ratios of the type

$$R=\frac{\sigma(\pi^-,\ \pi^-n)}{\sigma[(\pi^+,\ \pi^+n)+(\pi^+,\ \pi^0p)]}$$

showed that the picture is not so simple because the experimental values of R turned out to be two to three times lower than the theoretical values.[2] The emerging situation came to be characterized "dramatic,"[3] unsolved (π, πN) puzzle,"[4] etc. More than 150 experimental and theoretical investigations concerning this problem were carried out (see, for example, Ref. 5). The methods of radiochemistry and γ-spectroscopy of the residual nuclei refined the functions $\sigma(E_\pi)$ and $R(E_\pi)$ and in one- and (less frequently) two-shoulder experiments, the secondary light particles were measured, but only in a narrow range of their kinematic variables, which did not permit making an unambiguous assessment of the correctness of any one numerous models proposed. It became evident that experiments under conditions of total geometry and without limitations on the kinematics were required and, in addition, the choice of the specific form of the target nucleus did not have a decisive significance, since the pattern of the process was typical for all light and medium nuclei investigated. Such investigations were performed in 1970–1981 with the help of emulsion cameras using the nuclei ^{12}C, ^{14}N, and ^{16}O with $\pi^\pm$ meson energies of 60, 112, and 170 MeV. The integral and differential cross sections of the reactions (π^+, π^+p) (1), (π^+, π^0p) (2), and (π^-, π^-p) (3) and all other basic characteristics of the process, including the energy spectra of the secondary protons, their angular distributions, the momentum spectrum of the residual nuclei, the distribution over the Treiman-Yang angle (as is well known, in the case of direct quasifree scattering of particles by a nucleon inside a nucleus, when the pole approximation is realized, this distribution is isotropic), and different correlation dependences were measured. It turned out that all these characteristics depend on the sign of the bombarding mesons and to a lesser extent on their energy. The momentum spectrum of the recoil nuclei, the energy spectrum of the protons, and the distribution over the Treiman-Yang angle are most sensitive to the sign of the meson. Figures 1 and 2 show that the reaction (π^-, π^-p) is characterized by a large momentum transfer to the residual nucleus and by a softer proton energy spectrum, while the distribution over the Treiman-Yang angle is much more anisotropic than occurs

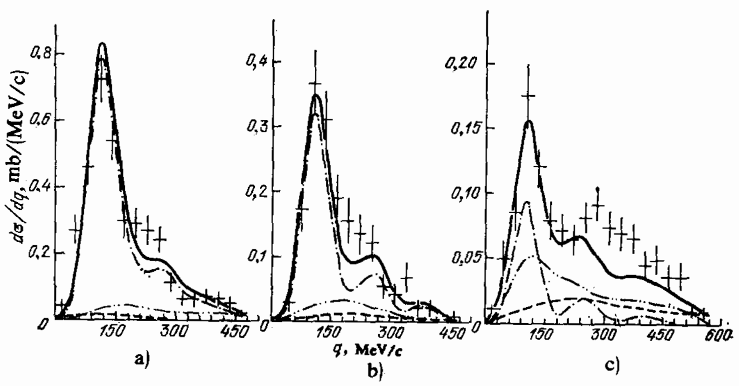

FIG. 1. Momentum spectrum of residual nuclei in the laboratory system with a pion energy of 170 MeV in reactions (1) (a), (2) (b), and (3) (c). The points indicate the experimental values. Computed curves: dot-dashed curves indicate pole knockout of the nucleon; the dashed curves indicate quasielastic knockout of the residual nucleus; the dash-double-dot curves indicate a two stage mechanism; and the continuous curve indicates the sum of all three mechanisms.

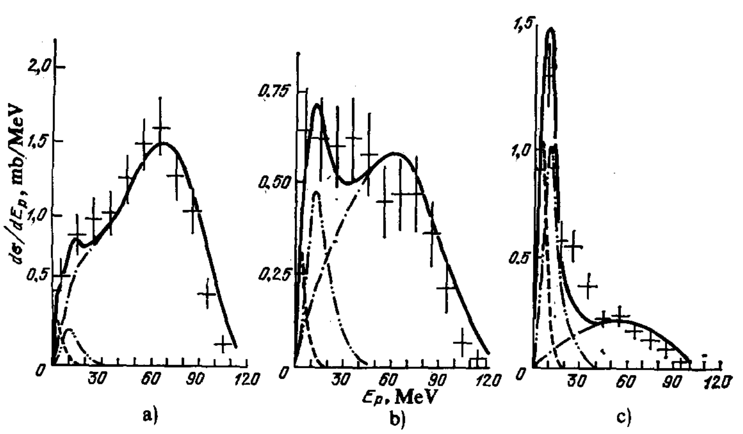

FIG. 2. Proton energy distribution in the laboratory system with a pion energy of 170 MeV in reactions (1) (a), (2) (b), and (3) (c). The points indicate the experiments. The computed curves are the same as in Fig. 1.

in the experiment with π^+ mesons.

All the experimental data obtained were analyzed using the theory of direct nuclear reactions, proposed by I. Shapiro.[6] The most complete experimental check of the applicability of the pole approximation was performed for the reaction with low momentum transfer to the nucleus ($q \leqslant 150$ MeV/c). Of the nine points in the program for identifying the pole mechanism,[7] all were realized with the exception of the polarization measurements. Of these, three corresponded to the most general assumptions: dependence of the absolute cross section on the pion energy, absolute differential cross sections (effective numbers of nucleons), and the dependence of the isotopic ratios on the momentum q. It was demonstrated that for small q, the pole mechanism for knocking out a nucleon dominates. The admixture of other mechanisms increases with increasing q and it is greater in the experiment with π^- mesons.

The new regularities, observed in the total experiment, represent a qualitatively new step, the next level of understanding of the mechanisms of (π, πN) reactions. The totality of the data on reactions (1)–(3) can be satisfactorily described within the framework of three mechanisms. These include: pole knockout of nucleon (the recoil nucleus is the spectator), quasielastic scattering by the residual nucleus (the nucleon is the spectator), and inelastic scattering of the pion with excitation of the nucleus and subsequent emission of the nucleon from the nucleus (two-stage process). The kinematic regions where three mechanisms dominate were established. Their role depends strongly on the energy and sign of the pion and reflects the characteristics of the elastic πp scattering cross sections. At resonance, the π^+p scattering cross section exceeds the π^-p cross section by approximately a factor of nine. For this reason, the knockout of a nucleon is to a large extent manifested in channel (1). On the other hand, the difference in the elastic πN-scattering cross sections has virtually no effect on the two other mechanisms, so that they will appear to be stronger in the (π^-, π^-p) channel. From here it is clear how to resolve the contradiction between the good description of the excitation functions of the reaction (π, πN) by the model of quasielastic knockout of a nucleon and the sharp deviation of the isotopic ratios from their corresponding elastic values. The explanation lies in the fact that the mechanisms, different from direct knockout of a nucleon, operate predominantly in the (π^-, π^-p) channel and to a lesser extent in the (π^+, π^+p) and (π^+, π^0p) channels. In this case, their role increases with increasing momentum q. A graphic illustration of this is the approach of the isotopic ratios to their corresponding free values as the restriction to small momenta q is made.

Further developments of investigations of direct nuclear reactions are: a) realization of the program of the pole mechanism in experiments using other particles; preliminary data on the reaction (K^+, K^+p) on ^{12}C and ^{16}O nuclei with a momentum of 0.85 GeV/c[8] support the pole mechanism of proton knockout by kaons with small q; b) correct inclusion of final-state interactions of particles; the nature of the motion of the singularities of the corresponding amplitudes was investigated experimentally for the first time in the works discussed and the contribution to the cross section reaction (3) corresponding to rescattering of nucleons by the residual nucleus was estimated; c) polarization measurements.

The material on which this report is based was published in the journal Yadernaya Fizika (**11**, 285 (1970); **13**, 478 (1971); **19**, 45 (1974); **21**, 950 (1975); **22**, 1073 (1975); **25**, 1150, 938 (1977); **27**, 599, 1452 (1978); **29**, 1143 (1979); **30**, 626 (1979); **31**, 1139 (1980)) and in Refs. 5 and 8.

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Translated by M. E. Alferieff