serve as an illustration of the foregoing.[1]

In conclusion, we note that a modification of the van der Waals forces (interaction "complex + complex"), similar to that examined above, is possible only when very rigid conditions are satisfied.

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M. M. Makarov, G. Z. Obrant, and V. V. Sarantsev, *Splitting of the deuteron by π-mesons with intermediate energies*. The interest in interactions of intermediate-energy π-mesons with deuterons stems from several factors.

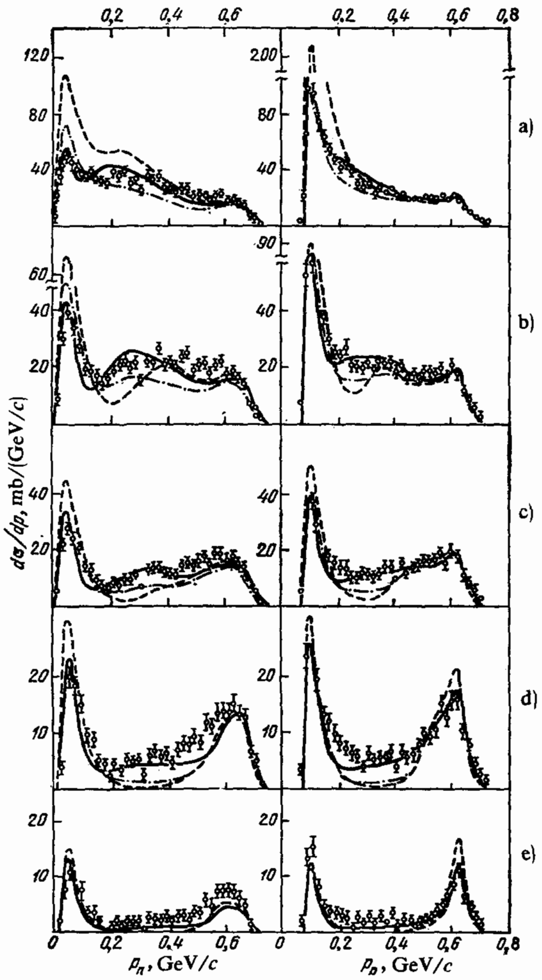
a) possibility of making progress in understanding the mechanism of the process in the region where the Glauber-Sitenko diffraction theory is inapplicable[1];

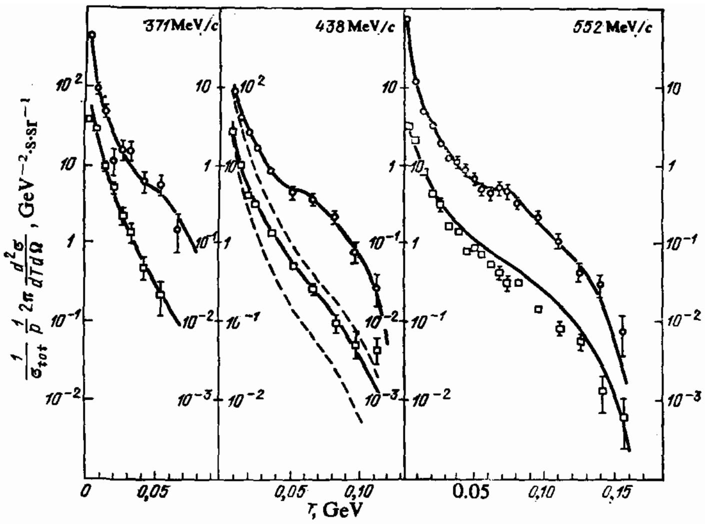
b) solution of the problem of dibaryon resonances[2] and observation of quarks in nuclei[3];

c) clarification of the role played by π-mesons in the formation of cumulative nucleons accompanying the interaction of high-energy hadrons with nuclei.

The mechanism of the process of splitting of the deuteron by pions with energies of several hundred MeV is determined primarily by single scattering of a π-meson by nucleons in the deuteron, by interaction of two nucleons in the final state, and by double rescattering of the pion.[4] Amplitudes with rescattering multiplicity exceeding two make a small contribution due to the fact that the conditions for the impact approximation are satisfied[5] ($U\tau \ll 1$, U is the characteristic nuclear potential in the deuteron) and due to the smallness of the parameter $\sigma_{\pi N}/4\pi R^2$ ($\sigma_{\pi N}$ is the pion-nucleon scattering cross section, R is the radius of the deuteron). Each of the three contributions mentioned above has distinguishing features, according to which it can be identified in the experiment. The single-scattering amplitude has a characteristic peak at 45 MeV/c in the momentum distribution of the nucleon, not participating in πN scattering (the nucleon is a "spectator"). The interaction of two nucleons in the final state has a peak at low relative proton-neutron energies and rapidly "dies away" with increasing momentum q transferred to the pion. The double scattering amplitude of π-mesons has a sharp singularity with respect to the energy variable ΔE, corresponding to nonconservation of energy with the transition from the initial state into the intermediate state at a distance of the nucleon at rest in the deuteron (peak with $\Delta E = 0$).[4] A general feature of the physics of the interaction of pions with energies of several hundred MeV with a compound system is the presence of a Δ (3,3) resonance in the πN amplitude, which greatly increases the contribution of double scattering.

Figures 1 and 2 show some results of an experiment on studying the process $\pi^- d \to \pi^- pn$, performed at the Leningrad Institute of Nuclear Physics of the USSR Academy of Sciences using the 35-cm deuteron bubble chamber,[6–9] as well as their description by a theory that includes multiple and double interaction of particles, as well as the Fermi motion of the nucleons. The momentum spectra (see Fig. 1) of the neutrons (on the left) and protons (on the right) with an initial pion momentum of 438 MeV/c in different parts of the phase volume with respect to the transferred momentum q (the entire range of q (a); $q > 0.3$ GeV/c (b); $q > 0.4$ GeV/c (c); $q > 0.5$ GeV/c (d); and, $q > 0.6$ GeV/c (e)) demonstrate the contribution of different amplitudes to the process. The initial neutron spectrum (see Fig. 1) shows that the regions dominating the different amplitudes strongly overlap and the peak at the momentum ≈45 MeV/c from the "spectator" neutron is manifested very weakly against an intense background of other processes. After the small transferred momenta q are excluded (in this case, recoil neutrons in the amplitude with the "spectator" proton are excluded in the soft part of the spectrum), this peak begins to dominate for small momenta and a single amplitude with the "spectator" neutron is thus singled out. It is evident from a comparison of the theoretical curves in Fig. 1c and the experimental dis-





tributions that a theory, taking into account all amplitudes (continuous curve), generally correctly describes the experimental data. It should be emphasized that the theory does not contain adjustable parameters and uses only the wave function of the deuteron and the pion-nucleon amplitudes. Comparison of the dashed (single interaction) and dot-dashed (pn interaction added in the final state) curves shows that there is strong destructive interference between these amplitudes. The double pion scattering amplitudes at small nucleon momenta likewise interfere destructively with other amplitudes (compare the continuous and dot-dashed curves) and, on the whole, the contribution of double scattering is significant. For sufficiently high transferred momenta ($q \gtrsim 0.4$ GeV/c), this contribution becomes determining outside the region where the single scattering amplitudes dominate and, in addition, rescattering occurs at large angles, i.e., they have a considerably non-Glauber character. The contribution of double scattering of the pion is also observed in the experiment in the form of a peak in the distribution with respect to the energy variable ΔE.[8]

The significance of pion rescattering is most clearly evident in the cumulative nucleon spectra, where the effect which has been called the "resonance amplification effect",[7] whose experimental manifestation is demonstrated in Fig. 2, was observed. The energy spectra of protons (squares) and neutrons (circles), exiting into the backward hemisphere, were measured for three values of the initial pion momentum: 371, 438, and 552 MeV/c.[7] It is evident that at all three energies, the spectra of the cumulative neutrons and protons differ in shape. The proton distributions at energies exceeding 30 MeV exhibit the usual experimental drop of the invariant cross section. The neutron distribution has a broad excess in the energy range 60–80 MeV. Purely qualitatively, this difference in the nucleon spectra can be explained as follows. After scattering by one of the nucleons in the deuteron, the π^- meson loses its energy and changes the direction of motion so that the scattering by the second nucleon can lead to ejection of the nucleon into the backward hemisphere. The scattering amplitude for the second collision can become very high as the Δ (3,3) resonance is approached, and since in this region the cross section for elastic π^-n interaction is larger than the cross section for π^-p scattering by almost an order of magnitude, this effect of resonance amplification should be more strongly manifested in the neutron spectrum.

The curves in Fig. 2 show the theoretical description of the experimental data: the continuous curve is the same as in Fig. 1; the dashed curves correspond to exclusion of rescattering of the π-meson. It is evident that the theory describes effective resonant amplification both qualitatively and quantitatively at all energies, and the contribution of rescattering is determining both in the neutron and proton distributions.

The observed effect can be significant for high-energy physics, since a large number of π-mesons is created in the interaction of particles with nuclei. Pions with energies of several hundred MeV must lead to analogous effects in cumulative nucleon spectra.

The reaction $\pi d \to \pi pn$ was studied at the meson factory in Los Alamos for incident π-meson energies in the region of the Δ (3,3) resonance (momentum 340 MeV/c). The experimental data in Ref. 10 correspond to two kinematic regions; a) region of quasielastic scattering (low neutron momentum); b) region far from the quasielastic scattering (large momenta of the two nucleons). In the first region, the results of the experiment corresponded to a single interaction, while in the second region, the data could be described theoretically only after adding diagrams with a dibaryonic resonance ($^5S_2N\Delta$ resonance with mass 2.17 GeV). Based on this, it was concluded in the work that a signal was observed from the dibaryonic resonance with mass 2.17 GeV. However, in Refs. 11–13, the Los Alamos data were described successfully with a systematic analysis using the theory of multiple scattering without invoking dibaryonic resonances. Comparison of different theoretical approaches[11,12] with experiment likewise shows that the existing data in the region of the Δ (3,3) resonance also do not show any significant effects of rescattering of particles with multiplicity exceeding two.

Thus the problem of inelastic interaction of pions with a few nucleon system is solved in the entire intermediate-energy range. Effects arising due to the presence of the Δ (3,3) 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

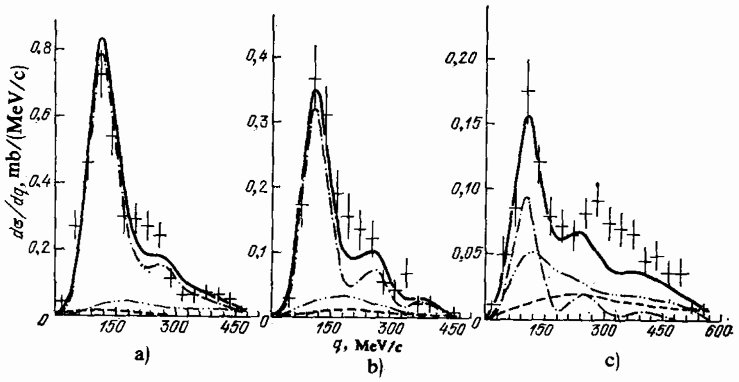

FIG. 1. Momentum spectrum of residual nuclei in the laboratory system with a pion energy of 170 MeV in reactions (1) (a), (2) (b), and (3) (c). The points indicate the experimental values. Computed curves: dot-dashed curves indicate pole knockout of the nucleon; the dashed curves indicate quasielastic 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.