Backward scattering of pions by nucleons

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Backward elastic scattering of pions by nucleons is an elementary form of excitation with baryon exchange. The backward scattering cross section is very small and decreases rapidly with increasing energy. The cross section becomes maximal when the scattering angle approaches 180°, i.e., a peak is observed in the backward scattering. In contrast to forward scattering, in backward scattering the processes in which positive and negative pions participate are not similar. This is confirmed by the exchange character of the backward scattering. In the energy interval up to 5 GeV, backward scattering has an extremely pronounced resonant character, due to the influence of the s-channel baryon resonances. Experimental data on backward scattering in the intermediate energy region (up to 20 GeV) are satisfactorily described by the Regge theory of complex angular momenta. The energy dependence of the cross section agrees with the model with linear baryon trajectories. In the Serpukhov-accelerator energy range (20–40 GeV), however, a weakening of the energy dependence is observed in the backward π^-n scattering. It is difficult to reconcile this behavior within the framework of the Regge phenomenology, with the linear form of the nucleon trajectory. A phenomenon that has a bearing on the observed behavior of the backward scattering at high energies was unexpectedly observed in an entirely different region. A phase-shift analysis of πN scattering at low energies (to 1 GeV) has shown that one of the partial waves (corresponding to the quantum numbers of the nucleon) experiences an appreciable rise when the energy approaches zero. It turns out that this singularity can be connected with the asymptotic behavior of the backward scattering. The two phenomena—the behavior of the backward scattering at high energies and the singularity of the partial wave near zero—indicate in a consistent manner that the effective spin of the nucleon reggeon greatly exceeds the value that follows from the linearity of the nucleon trajectory. In contrast to backward π^-n scattering, the behavior of backward π^-p scattering (pure Δ exchange) reveals no singularities whatever in the Serpukhov-accelerator energy interval and continues to have the same energy dependence as observed at lower energies. As to the angular distributions, a very narrow backward peak is observed in the π^-p scattering, and has a slope comparable with the peak of the $\pi^-n(\pi^+p)$ scattering. The closeness of the $\pi^{\pm}n$ angular distributions, which has been observed for the first time at high energies (25–40 GeV), suggests the possibility of a geometrical interpretation—scattering by an extended object. The analogy between backward scattering of pions by nucleons and glory—an optical effect observed when light is backscattered from a raindrop—is discussed. In conclusion, radiative corrections to backward scattering are considered.

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CONTENTS

1. BEGINNINGS OF THE INVESTIGATION OF PION-NUCLEON BACKWARD SCATTERING. SCATTERING IN THE "RESONANCE" ENERGY REGION.

The investigation of scattering is a direct method of studying the interaction of elementary particles. Forward scattering (~0°), scattering at large angles (~90°), or backward particle scattering (by 180°) cast light on different aspects of the interaction.

The history of the investigation of backward scattering traces its beginning to Rutherford's famous experiment, in which backward scattering of α particles from a thin mica foil were observed. These observations led to the discovery of the atomic nucleus. Rutherford "was lucky" with the α-particle energy, which turned out to be suitable for this case: large enough to "feel" the structure of the atom, but small enough not to damage the nucleus. Under this condition, the interpretation of

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particle scattering as scattering of classical objects turned out to be correct. Rutherford's *formula*, which he derived on the basis of Newton's mechanics for the interaction of charged particles, turned out to be accurate enough and suitable for this case.

With increasing bombarding-particle energy, however, this treatment turns out to be inconsistent. In the general case, the behavior of the particles must be treated quantum-mechanically. Moreover, in the interaction of high-energy particles, the "strength" of the particles becomes roughly speaking insufficient: the interaction process is accompanied by particle production, absorption, and conversion into one another. Even in elastic interactions, where the initial particles are preserved, intense production and absorption of virtual particles takes place. Forward elastic scattering has little effect on the internal structure of the colliding particles, and the particle interaction is diffractive in character. In Regge language, such a process is described in terms of pomeron-reggeon exchange with the quantum numbers of vacuum; this exchange does not alter the nature of the interacting particles. The forward scattering cross section is large and, like all pomeron-exchange processes, depends little on the energy.

With increasing scattering angle, the cross section decreases rapidly and reaches a minimum at a scattering angle close to 90° in the c.m.s. Increasing the energy of the interacting particles leads to an exceedingly rapid decrease of the cross section. This is easily understood, inasmuch as in 90° scattering the transverse-momentum transfer is maximal, and there is an extremely low probability that the particles can exchange a momentum that reaches many dozens of gigaelectron volts at high energies without disintegrating, owing to the very small "strength" in the particles.

From this point of view it might seem that the backward scattering cross section should be even smaller, since the particles exchange a momentum equal to the momentum of the incident particle. However, we can treat backward scattering differently, as an "inelastic" process, in which the incident particle is converted into a target particle that continues to move in the same direction without a noticeable change of momentum. Although in backward scattering the particles that remain in the final states are the same as in the initial state, this is in a certain sense a more "inelastic" process in comparison, say, with forward charge exchange ($\pi^- p \to \pi^0 n$), inasmuch as backward scattering is also accompanied by "charge exchange," but it is the baryon number which is exchanged. Of all the quantum numbers, baryon-number exchange is the most difficult, since the baryon number is connected with the large mass of the exchange particle. For this reason, the backward-scattering cross section is small and decreases with increasing energy of the interacting particles.[1)] This cross section, however, is not as small and does not decrease as rapidly with energy as in 90° scattering (Fig. 1). Thus, backward scattering at high energies must be regarded as "baryon charge exchange," and the cross section of this process is larger the smaller the transverse momentum transfer. We have thus reached the conclusion that backward scattering should have a peak at 180°. The theoretical prediction that a peak exists in backward scattering is one of the fundamental predictions, since it follows from the most general principles of the theory, which do not depend on any concrete model concepts.[1]

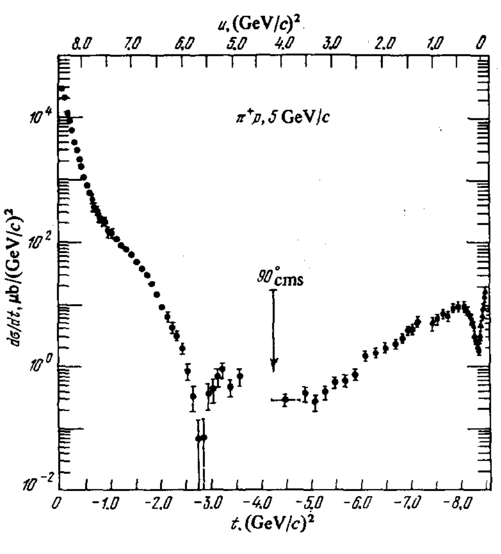

FIG. 1. Dependence of the $\pi^+ p$ elastic-scattering cross section on the square of the momentum transfer.

Although we have started our discussion with Rutherford's experiments, the history of the investigation of backward scattering at high energies is quite recent. And while at the present time backward scattering is studied by the leading laboratories of the world, and the research is carried out in the entire attainable energy range, as recently as in 1963 the experimental estimate of the pion-nucleon backward scattering cross section for energies exceeding 1 GeV fluctuated in the range from several to several thousand μb/sr.[2,3] The first reliable estimate of the backward scattering of pions by neutrons of carbon nuclei was obtained in 1964 at our Institute.[4] It was observed that the cross section of the process depends strongly on the energy and changes from 600 to 20 μb/sr in the range 1.5–4.5 GeV. This exploratory study was performed by two procedures, with a propane bubble chamber and with a large cylindrical spark chamber. Both members yielded comparable results. In the same 1964, The Aachen–Berlin–Birmingham–Bonn–Hamburg–London–Munich collaboration measured at CERN with a bubble chamber backward $\pi^+ p$ scattering at 4 GeV (19 ± μb/sr).[5] Later investigations have shown these cross-section estimates to be correct, so that these two studies should be re-

[1)]The "intuitive" assumptions that baryon exchange is made difficult by the large mass of the baryon are based on the linearity of the Regge trajectories. If the baryon trajectories are nonlinear, on the other hand, then the foregoing conclusion concerning the behavior of backward scattering may turn out to be incorrect. This is discussed in greater detail in Ch. 3.

garded as the first in which backward scattering of pions by nucleons at high energies was observed.

Within a relatively short time, impressive results were obtained in the investigation of backward scattering of pions by nucleons.

a) Foremost was the observation of the backward peak and of the singularities in the angular distribution.[6–8] Thus, in the π^+p reaction, the peak in the 180° region turned out to be very narrow (much narrower, for example, than the diffraction peak in forward scattering). This was first demonstrated in 1965 at our Institute[6] in an investigation of the isotopically invariant π^-n scattering channel. These data were soon afterwards confirmed at Brookhaven.[7] Later investigations[8] have shown that the differential cross sections for the scattering of π^+ mesons by protons have a complicated structure (Fig. 2). Thus, the narrow backward peak is preceded by a deep dip in the cross section at a squared momentum transfer $u \approx -0.16\ (\mathrm{GeV}/c)^{-2}$. On the other hand, in the π^-p reaction the backward peak turned out to be very broad[8] (much broader than the forward diffraction peak), without any irregularity whatever in the momentum-transfer region $|u| < 1\ (\mathrm{GeV}/c)^{-2}$ (see Fig. 2).

b) The differences in the angular distributions of the backward π^+p and π^-p scattering correspond also to a large difference in the cross sections. The cross section ratio $\sigma(\pi^+p)/\sigma(\pi^-p)$ in 180° scattering ranges from 5 to 7. The large difference in processes with particles of opposite signs (and this holds also for kaons[9]) is a remarkable feature of backward scattering. Indeed, in forward scattering processes (elastic scattering, total cross section), the differences between reactions with particles and antiparticles are small and vanish with increasing energy (the Pomeranchuk theorem[10]). In final analysis, this is the consequence of the fact that exchange of a reggeon with the quantum numbers of vacuum predominates. On the other hand, the differences in the behavior of particles of opposite sign indicate that exchange of particles with different quantum numbers takes place.

c) There is also no similarity between the energy dependences of the π^+p and π^-p backward scattering cross sections. The most important here was the observation of a resonant character of the behavior of cross section of 180° pion-nucleon scattering at an energy in the so called resonance region ($\lesssim 5$ GeV).[6,11] A structure in the energy dependence of the backward scattering (in the π^-n channel) was first observed in the already mentioned investigation of our Institute (CITEP).[6] Kormanyos *et al.*[11] have investigated thoroughly the energy dependence of 180° elastic π^-p scattering and observed a number of minima and peaks (Fig. 3). Particular attention attracted the minimum of the cross section at a momentum 2.15 GeV/c. In an interval of several tenths of one GeV/c, the cross section decreased by two orders of magnitude, after which it again increased by one order of magnitude. This minimum in the cross section corresponded exactly to the position of the $N(2190)$ isobar. The connection observed in[11] between the behavior of the backward scattering and the masses and quantum numbers of their resonances has made it possible to determine, from the character of the energy dependence, certain hitherto unknown quantum numbers of the resonances (for example, negative parity for $N(2190)$ and $N(2650)$, positive parity for $\Delta(2420)$ and $\Delta(2820)$, etc.).

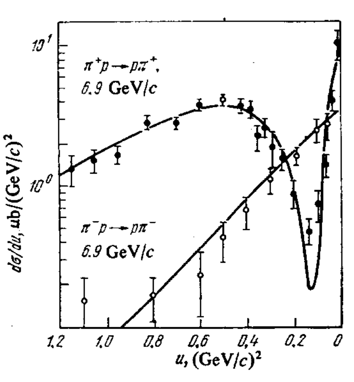

FIG. 2. Plots of the cross sections of backward π^+p and π^-p scattering vs the squared momentum transfer.

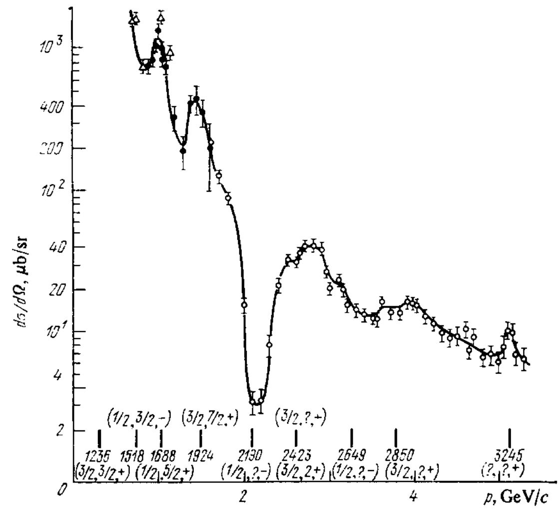

FIG. 3. Momentum dependence of the cross section of 180° π^-p scattering.

The resonant character of the energy dependence, and the connection between the scattering and the resonances can be understood in the following manner. If the isobar production process $\pi^\pm + p \to N^*(\Delta) \to \pi^\pm + p$ followed by decay into the same particles is possible at some particular energy, then the backward scattering is indistinguishable from isobar decay with backward pion emission. The reaction with isobar production has an energy dependence of resonant character. Obviously, backward scattering reflects this resonant character in the region of isobar production. The resonant behavior should be strongly pronounced, since the backward scattering cross section is small and the influence of the s-channel resonances turns out to be very large.

The resonant character of the energy dependence in the backward π^+p scattering reaction was investigated in detail in 1967–1968 by the Dubna group,[12] at Brookhaven,[13] and at our Institute[14] (π^-n). The energy dependence of the 180° π^+p scattering has an equally pronounced resonant character (Fig. 4), determined by Δ-isobar production in the s channel.

In the study of our Institute,[14] besides the energy dependence of 180° scattering, investigations were made also of the angular distributions of the backward scattering in the region of 180°. The angular distributions also reflect the interference character of the interactions. Whereas in the region of the cross-section maxima the angular distributions have clearly pronounced peaks near 180° ($p = 2.6$ and 3.8 GeV/c), the distribution changes have a different character in the region of the minima. The principal minimum in the momentum range 1.9–2.1 GeV/c, reveals more readily a decrease of the backward-scattering cross sections towards 180° (Fig. 5).

2. BACKWARD SCATTERING OF PIONS BY NUCLEONS IN THE "POST-RESONANCE" INTERMEDIATE ENERGY REGION. LINEAR BARYON TRAJECTORIES.

Let us examine first how the theory describes backward scattering of pions by nucleons. Unfortunately, we do not have a theory of strong interactions in general form. The reason is that the coupling constant in strong interactions is large. Perturbation theory, so successfully used in electrodynamics, does not work here, and no general method has been found for calculating the interaction under strong-coupling conditions. A satisfactory theory can be constructed for certain particular cases. The greatest expectations lie in an asymptotic approach, the gist of which consists of considering the processes in the region of very high energies, where the interactions are not made complicated by threshold phenomena, where the individuality of the particles is

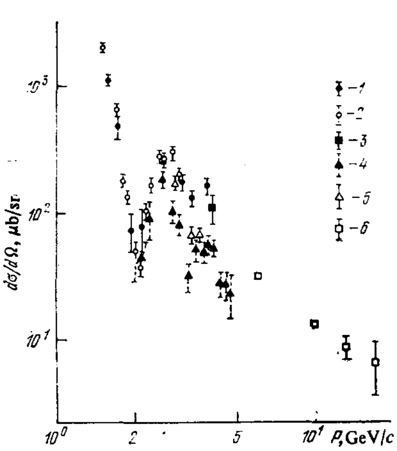

FIG. 4. Momentum dependence of the 180° π^+p (π^-n) scattering cross section. 1—ITEP, 1968; 2—Brookhaven, 1968; Cornell–Brookhaven, 1966; 4—Dubna, 1968; 5—CERN, 1968; 6—Cornell–Brookhaven, 1968.

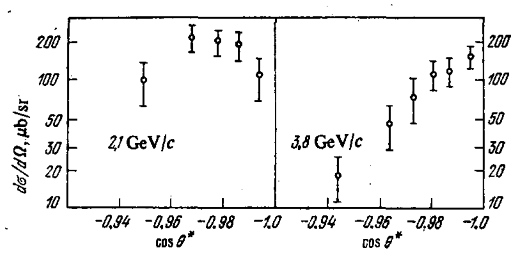

FIG. 5. Angular distributions of backward π^-n scattering at momenta 2.1 and 3.8 GeV/c.

gradually obliterated,[15] and there is hope that the description of the interaction becomes simpler. The most consistent and universal theory of the asymptotic interaction of hadrons is the Regge theory of complex angular momenta.[16] It is assumed in this theory that the main contribution to the interaction is made by exchange of a reggeon, which is an assembly of particles that are in a state with definite quantum numbers (baryon charge, isospin, and parity) and a variable spin that depends on the square t of the momentum transfer. The amplitude of the reggeon exchange is proportional to s^α, where α is the variable spin of the reggeon, s is the square of the energy in the c.m.s. ($s = (p_1+p_2)^2$, $t = (p_1-p_3)^2$, $u = (p_1-p_4)^2$, where p_i is the 4-momentum of the particle in the two-particle process $1+2\to 3+4$). At high energies, out of the infinite number of singularities that are characterized by the difference α_i, the principal singularity with the largest α is singled out. This is the essence of the asymptotic approach. On the other hand, since α depends on t, and decreases with increasing momentum transfer, the region of small t is singled out. Thus, not only the forward scattering region, but also the backward scattering region is singled out.[17] In the latter case, the squares u of the momentum transfer should be small. In analogy with forward diffraction scattering, the backward peak is due to the decrease of α with increasing square u of the momentum transfer, except that here $\alpha(u)$ is the principal singularity of the baryon reggeon. In general, in reggeistics the diffraction picture takes place in any two-particle interaction forward or backward, elastic or exchange, provided only that the process can be described by reggeon exchange.

As already noted, the asymptotic energy region is far enough from the threshold phenomena to permit the resonances (in the s channel) to exert a direct influence on the particle scattering. Does this mean that if we advance far enough in energy into the region where the dependence has a smooth character, where the particles become indistinguishable, that all connection with the particles is lost?

One of the merits of reggistics is that it has made it possible to observe a connection between a hitherto autonomous subject, particle scattering at high energies, on the one hand, and the spectrum of the resonances and elementary particles on the other hand. The point is that the reggeon has a definite set of quantum numbers and is by the same token connected with its constituent resonances and particles with the same quantum numbers; moreover, the value of α and its dependence on the momentum transfer, i.e., the factors that determine the dynamics of particle scattering in the asymptotic limit, are specified in a certain sense by the ratios of the spins and masses of the family of elementary particles and resonances with the given quantum numbers.

The amplitude of exchange of a fermion reggeon

$$M = F(u)\frac{1+\sigma\exp\{-i\pi[\alpha-(1/2)]\}}{\sin\{\pi[\alpha-(1/2)]\}}\left(\frac{s}{s_0}\right)^{\alpha-1/2} \tag{2.1}$$

(where $\sigma = \pm 1$ is the signature, $F(u)$ is a real function of u which cannot be determined in the theory, and $s_0 = 1$ GeV [2] is a dimensional constant) is defined in the physical region of negative values of u. For positive values of u, the amplitude (2.1) has physical meaning only at half-integer values of the spin α: for positive signature ($\sigma = +1$) at the values $\alpha = 1/2,\ 5/2,\ 9/2, \ldots$, and for $\sigma = -1$ at $\alpha = 3/2,\ 7/2,\ 11/2, \ldots$. The amplitude has poles at these points. If the poles are set in correspondence with real particles and resonances,[2)] then the so-called Regge trajectories are produced: nucleon trajectories α_{N_α} with $\sigma = +1$ and α_{N_γ} with $\sigma = -1$ for isotopic spin 1/2 and the Δ trajectory α_Δ with $\sigma = -1$ for isotopic spin 3/2 (Fig. 6).

The theory does not predict the shape of the Regge trajectory (this is natural, since there is no provision in this theory for the spectrum of the elementary particles and resonances), but in the theory $\alpha(u)$ is the only analytic function that describes the behavior of the scattering of the particles at high energies at $u < 0$, and the dependence of the spin on the mass for particles and resonances at $u > 0$. Let us see whether we can determine the shape of the trajectory by using this information. At small momentum transfers, the trajectory can be represented in the form of a series. Thus, for example, for bosons

$$\alpha(t) = \alpha_0 + \alpha' t + \alpha'' t^2 + \ldots \tag{2.2}$$

The behavior of the trajectories in the physical region at negative t (determined from experiments on forward scattering, charge exchange, etc.) as well as the position of the real particles for positive t, indicates that we can confine ourselves in (2.2) to the first two terms, i.e., the boson trajectories are linear in t.

In the case of backward scattering the picture is more complicated.[17] The baryon reggeon manifests itself as a particle at half-integer values of the spin, i.e., it is a fermion. In the case of exchange of a particle with a half-integer spin, the propagator contains the mass raised to the first power. For reggeons, the role of the mass is played by $\sqrt{u}$ (u is the square of the c.m.s

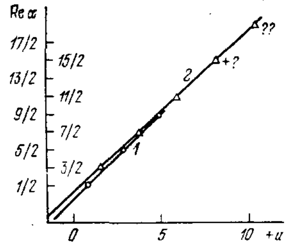

FIG. 6. The linear Regge trajectories N_α and Δ. 1—$\alpha_{N_\alpha} = -0.37 + 0.99u$; 2—$\alpha_\Delta = 0.10 + 0.91u$.

energy in the u channel). Therefore the parameter expansion of the baryon trajectory is $\sqrt{u}$:

$$\alpha(\sqrt{u}) = \alpha_0 + \beta\sqrt{u} + \alpha' u + \ldots \tag{2.3}$$

However, the total amplitude must not contain the additional complexity connected with the quantity $\sqrt{u}$ that appears in fermion exchange. The amplitude is therefore determined not by one pole but by a pair of poles of opposite parity, and there are two ways of getting rid of the extra complexity.

The first possibility is that any fermion corresponds to another fermion of equal mass and opposite parity, i.e., *parity degeneracy* takes place. In this case the trajectory does not contain terms with odd powers of $\sqrt{u}$:

$$\alpha(u) = \alpha_0 + \alpha' u + \ldots \tag{2.4}$$

The situation is very similar to that which takes place for boson exchanges, and since the real baryon positions are close to the straight lines, the baryon trajectories can be *linear* in u (Fig. 6).

The other possibility is that the fermion trajectories of opposite parity are complex-conjugate. In this case

$$\alpha(\sqrt{u})_\pm = \alpha_0 + \alpha' u \pm \beta\sqrt{u}, \tag{2.5}$$

and there is likewise no complexity in the total amplitude.

If the first possibility (parity degeneracy) is realized, then the question of the shape of the trajectory is solved: the baryon trajectories are straight lines (we can neglect the term $\propto u^2$), and the positions of the particles and resonances on the trajectory specify uniquely the behavior of α as a function of the momentum transfer in the physical domain of negative u, where it determines the particle scattering.

It is easily seen that baryon exchange leads to a strong decrease of the cross section for backward scattering of pions by nucleons as the energy is increased. Since

$$\frac{d\sigma}{du} \sim \frac{1}{s}|M|^2 \sim \left(\frac{s}{s_0}\right)^{2\alpha-2}, \tag{2.6}$$

and the baryon trajectories passing through the resonances are

$$\begin{aligned} \alpha_{N_\alpha} &= -0.37 + 0.99u, \\ \alpha_\Delta &= +0.10 + 0.91u, \end{aligned} \tag{2.7}$$

[2)]If α is complex at half-integer values of Reα, then the amplitude describes an unstable particle—a resonance.

it follows that for processes determined by the nucleon pole we have

$$\left(\frac{d\sigma}{du}\right)_{u=0} \propto \left(\frac{s}{s_0}\right)^{-2.7} \propto E^{-2.7}, \tag{2.8}$$

and for the processes with the Δ trajectory

$$\left(\frac{d\sigma}{du}\right)_{u=0} \propto \left(\frac{s}{s_0}\right)^{-1.8} \propto E^{-1.8}. \tag{2.9}$$

It should be noted that the decrease of the cross section is steeper the larger the resonance mass at the smallest spin. Thus, the reason for the strong decrease of the cross section for backward scattering of pions by nucleons is that there are no light baryons with mass smaller than the nucleon mass; on the other hand, the nucleon trajectory gives the relation (2.8) cited above.

If we now investigate experimentally the energy dependence of the backward pion-nucleon scattering, we can obtain the behavior of the trajectories and of the principal singularities that determine the scattering process. We must first ascertain which singularities are decisive in backward pion-nucleon scattering at high energies. To this end we must resort to the relation between the different reactions. Thus, the backward $\pi^- p$ scattering reaction has in the u channel an isospin projection equal to 3/2 and can therefore proceed via Δ-reggeon exchange. On the other hand in the $\pi^+ p$ reaction third isospin projection is equal to 1/2 and the backward $\pi^+ p$ scattering is determined both by the nucleon (N_α) trajectory and by the Δ trajectory.[3)] The isotopic relations between the reactions are derived with the aid of Clebsch-Gordan coefficients. Thus, the $\pi^- p/\pi^+ p$ cross-section ratio is 0 : 2 if the N pole is decisive in both reactions, and 9 : 1 if scattering proceeds only via the Δ pole.

Experimental investigations of the backward scattering of π^+ and π^- mesons by protons in the energy interval 5.9–17 GeV were realized by two groups: Cornell–Brookhaven[18] and Brookhaven–Carnegie-Mellon.[19] It follows from these measurements that at the indicated energies, just as at the lower energies, the backward $\pi^+ p$-scattering cross section in the region $u = 0$ is appreciably larger (by five times) than the $\pi^- p$ cross section. The strong difference between the angular distributions still remains (a narrow peak with a dip for $\pi^+ p$ scattering and a broad peak for $\pi^- p$ scattering). It follows from these data that the nucleon residue greatly exceeds the residue for the Δ singularity, and therefore $\pi^+ p$ scattering is determined in the main by the nucleon pole. Regge models with linear baryon trajectories[20] satisfactorily describe backward $\pi^+ p$ scattering up to 17 GeV.

3)The N_γ trajectory is usually disregarded in $\pi^+ p$ scattering, since it has the smallest value of α at $u = 0$ (provided that the trajectories are linear). At high energies, the influence of the N_γ trajectory can be neglected.

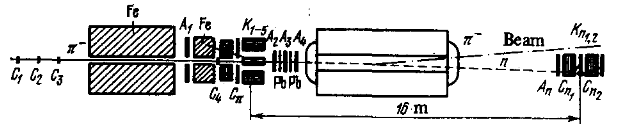

FIG. 7. Diagram of setup used in the ITEP experiments (1972). C_{1-4}, C_π, $C_{n_{1-2}}$—coincidence counters, A_{1-4}, A_n—anticoincidence counters—K_{1-5}, $K_{n_{1,2}}$—spark chambers, Fe—shield, Pb—lead converters.

However, as we have seen, in the case of linear trajectories one must expect the energy dependence for the nucleon poles to be steeper than for the Δ pole, the N_α pole should fade out more rapidly (cf. (2.8) and (2.1)), and with increasing energy the Δ pole should ultimately replace the N pole in its influence on the $\pi^+ p$ scattering, even though the N_α residue exceeds the Δ residue. These considerations have enabled Borger and Cline[21] to predict that at ~35 GeV the backward $\pi^- p$-scattering cross section should exceed the $\pi^+ p$-scattering cross section. Thus, the definite conclusions concerning the behavior of the trajectory, based on the energy dependence of the backward scattering cross section, can be obtained only through an experimental investigation at energies that are attainable with the Serpukhov and Batavia accelerators.

3. BACKWARD $\pi^- n$ SCATTERING IN THE ENERGY INTERVAL OF THE SERPUKHOV ACCELERATOR. NONLINEAR BARYON TRAJECTORIES

In 1972 a group at our Institute[22] measured the elastic scattering of π^- mesons by neutrons in the energy interval 20–40 GeV. The measurements were made with the Serpukhov accelerator. The setup is shown in Fig. 7. Here, as in the preceding investigations of our Institute,[4,6] the products of the interaction of the pions and the target were registered with maximum efficiency (the target was surrounded by spark chambers) and the forward-traveling charged particles and γ quanta were suppressed in a system of "anticounters." In addition (just as in the ITEP study[14]), a kinematic principle was used to separate the elastic reaction by measuring the angles of the backward scattered pion and the forward scattered recoil neutron, which was registered in the spark chambers of the neutron detector. Particular attention was paid to the possibility of exposing the installation to a maximum beam intensity.[4)] To this end, a

4)The need for this is quite obvious, if it is recognized that the cross section of the process is very small and decreases with energy. The extent to which the difficulties in the measurement of the backward scattering increase with increasing energy is clearly seen, for example, in the Cornell—Brookhaven experiment[18] from the manner in which the errors increase in the experimental points on going to energies 13 and 17 GeV (see Fig. 9 below). At these energies only a handful of backward scattering events was observed.

clearing magnet was placed between the target and the neutron detector to deflect the primary beam away from the spark chambers of the neutron detector. In addition, a central opening was left in the forward spark chamber used that registered the back-scattered pions, to permit passage of the beam. These measures made it possible to use a beam intensity with an average level 5×10^5 particles per cycle at a dumping time 0.5 sec.

A one-meter solid deuterium target, cooled with liquid helium, was used in the experiment.

Figure 8 shows the angular distribution of the cross section for backward scattering of π^- mesons by neutrons at 40 GeV. The figure shows a sharp backward peak having in the narrow region near 180° a slope

$$\frac{d}{du}\left[\ln\left(\frac{d\sigma}{du}\right)\right]=26\pm6\ (\mathrm{GeV}/c)^{-2}\ .$$

Figure 9 shows the energy dependence $(d\sigma/du)_{u=0}$ in comparison with the Cornell–Brookhaven[18] π^+p data at energies 5.9, 10, 13.7, and 17.1 GeV. The comparison shows that the decrease of the scattering cross section begins to slow down with increasing energy. Whereas in the 5.9–10 GeV interval the slope of the decrease of the cross section with energy, proportional to $1/E^n$, is characterized by an exponent n larger than 2, for energies larger than 10 GeV the exponent already becomes smaller than 2. The exponent n is directly connected with $\alpha(0)$ ($\alpha(0)=1-(n/2)$, see (2.6)). Thus, at energies lower than 10 GeV we have $\alpha(0)<0$, which is characteristic of the nucleon pole (2.7), while for energies above 10 GeV we have $\alpha(0)>0$, as if the pure Δ exchange were decisive in the $\pi^-n(\pi^+p)$ scattering. However, such a rapid assumption of the roles of N_α by Δ in π^-n scattering should have led to a jumplike increase of the π^-p scattering cross section. The π^-p cross section was so much lower than that of π^+p at 16 GeV; on the other hand, if the Δ pole assumes the principal role in π^-n, then, as we have seen above, the π^-p cross section should exceed the $\pi^-n(\pi^+p)$ cross section by many times (9 : 1). As will be shown below, no increase of the π^-p cross section is observed with increasing energy. Thus, we arrive at the conclusion that the nucleon pole should remain predominant in $\pi^-n(\pi^+p)$ backward scattering, but the effective value of $\alpha(0)$ becomes positive. However, we do not known of any linear trajectories with

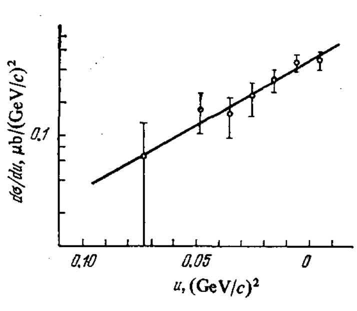

FIG. 8. Differential cross section of backward π^-n scattering at 40 GeV/c. $d\sigma/du = Ae^{Bu}$, $A=0.44\pm0.053$ μb (GeV/c^2), $B=26\pm6$ (GeV/c)$^{-2}$.

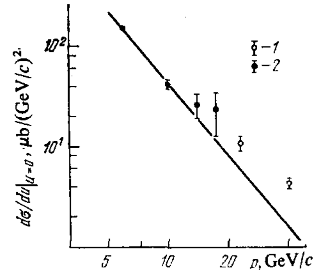

FIG. 9. Dependence of the backward $\pi^+p(\pi^-n)$ scattering cross section on the momentum. 1—ITEP, 1972; 2—Cornell–Brookhaven, 1968.

positive $\alpha(0)$ in the 1/2 isotope channel. Thus, either the backward-scattering amplitude contains non-Regge terms with $\alpha_{\mathrm{eff}}>0$ (we shall consider some of such models later on), or we must assume that the second possibility referred to above is realized (with nonlinear baryon trajectories (2.5)), and furthermore such that at $u=0$ the value of α becomes larger than that obtained with a linear trajectory. Then this leads unavoidably to a slowing down of the decrease of the cross section with energy.

Let us see whether nonlinearity of the baryon trajectories is possible (and within which limits).

Turning to Fig. 6, then it seems that the proximity of the resonances to the straight line is a very strong confirmation of the empirical rule that the baryon Regge trajectories are linear. This, however, is only a visual fallacy. Firstly, the trajectories do not pass through all the known resonances, and on the other hand the quantum numbers of some of the resonances that do lie on the trajectories are unknown. Secondly, the linearity of a trajectory means, as we already discussed, that the resonances are degenerate in parity. In the table, however, there are no cases when resonances of opposite parity coincide, with the possible exception of the pair $N(1688)5/2^+ - N(1670)5/2^-$, which might be regarded as a doublet, but then the nucleon $N(940)1/2^-$ should have a resonance of smaller mass as a doublet, and no such resonance was found. Thirdly and finally, the high reliability of the prediction of the ebhavior of the scattering, implied by the closeness of the resonances to the straight lines, is in fact illusory. It is possible to draw through the same resonance, with equally small deviations, the parabolas (2.5): $\alpha(\sqrt{u})=\alpha_0+\alpha'u\pm\beta\sqrt{u}$, for which (and this is important!) the coefficient β of the term u can be made quite large. But this alters completely the behavior of the scattering predicted by the positions of the resonances. Scattering in regions of small u (the only region where the theory "works") is determined principally by the quantities α_0 and β, and depends very little on α' (the term $\alpha'u$ is small at $u \ll 1$), whereas the passage of the trajectory near resonances is governed primarily by the coefficient α'. Thus, there is little connection between the passage of a trajectory near the resonances and its behavior in the region $u\lesssim0$, and the extrapolation is very far-fetched.

Here are some examples. The trajectories $\alpha_{N_\alpha} = -0.70+0.83u\pm0.5\sqrt{u}$ and $\alpha_\Delta=-0.20+0.83u\pm0.36\sqrt{u}$ pass through the largest number of presently known resonances, and describe simultaneously particles with

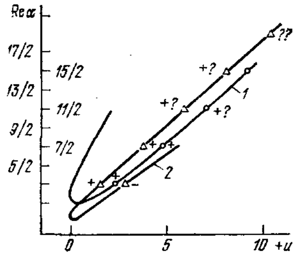

FIG. 10. Examples of nonlinear Regge trajectories 1—$\alpha N_\gamma = 1 + 1.207u \mp 1.50\sqrt{u}$; 2—$\alpha_\Delta = 0.20 + 0.83u \pm 0.36\sqrt{u}$.

positive parity if $\sqrt{u}$ is taken with the positive sign and particles with negative parity if $\sqrt{u}$ is negative (the nucleon trajectory for the spins 1/2, 5/2, and 9/2 yields mass values 0.939, 1.688, 2.223 and 1.537, which should be compared with the particles $N(939)1/2^+$, $N(1688)5/2^+$, $N(2220)9/2^+$, and $N(1535)1/2^-$; the Δ trajectory yields 1.238, 1.920, 2.420, 2.850, 3.220 if the positive sign is taken for u and 1.670 for the negative sign, and the corresponding particles are $\Delta(1236)3/2^+$, $\Delta(1950)7/2^+$, $\Delta(2420)11/2^+$, $\Delta(2850)?^+$ $\Delta(3230)?^?$ and $\Delta(1670)3/2^-$ (Fig. 10).

At these trajectories, the energy dependence of the scattering will be steeper in comparison with the linear trajectories: $(d\sigma/du) \propto E^{-3.4}$ for the N trajectories and $(d\sigma/du) \propto E^{-2.4}$ for the Δ trajectories (compare with the $\propto E^{-2.7}$ and $\propto E^{-1.8}$ dependences in the case of the linear trajectories). It is also possible to obtain positive values of α_0 in trajectories, for example $\alpha_{N_\alpha} = 0.5 + 1.58u - 1.48\sqrt{u}$. Then α passes through the point $(0.938)1/2^+$, $(1.688)5/2^+$ and $(2.140)9/2^+$ (cf. the particles), and the energy dependence of the scattering will be much weaker than in the case of linear trajectories.[5)]

The backward π^-p and π^+p scattering cross sections can not only fail to intersect at 35 GeV (we recall the predictions of[21]), but move apart altogether.

In the absence of the requirement that the trajectories be linear, we are left with no arguments for neglecting the influence of the N_γ trajectory on the π^+p scattering (see footnote 3). Moreover, this influence may turn out to be decisive. As a curious example, we cite the trajectory $\alpha_{N_\gamma} = 1.0 + 1.207u - 1.50\sqrt{u}$, which passes ideally through real resonances (cf. the values $\alpha_{N_\gamma}(1.520)3/2^-$, $(2.190)7/2^-$, $2.650(11/2^-)$, and $3.025(15/2^-)$ with the particles $N_\gamma(1520)3/2^-$, $N_\gamma(2190)7/2^-$, $N_\gamma(2650)?^-$, and $N_\gamma(3030)?^?$, and at which the cross section for backward scattering of π^+ mesons by protons at $u = 0$ *ceases to depend on the energy*: $(d\sigma/du)_{u=0} = \text{const}$. Of course, a trajectory of this kind would generate at positive sign $\sqrt{u}$ resonances of opposite parity with smaller masses, which do not occur in nature. This difficulty can be circumvented, however, for example by equating to zero the π^+p scattering amplitude at the corresponding points u. It is even possible to obtain about at the same time an exact description of the famous dip (at $u \approx -0.16\ (\text{GeV}/c)^{-2}$) in the angular distribution of the backward π^+p scattering.[6)]

We started our discussion of the Regge theory of complex angular momenta with the impressive fact that the resonances are connected with scattering. Unfortunately, we do not know how this connection is actually realized. The foregoing examples demonstrate that modern theory, in essence, does not restrict the behavior of the backward scattering of pions by nucleons (more accurately, an energy dependence of the backward scattering is admissible within the limits from $E^{-3.5}$ up to E^0).

Our net result is thus the following:

1. The experimental results on backward π^-n scattering at high energies indicate that the baryon trajectories can be nonlinear.

2. The Regge theory of complex angular momenta by itself does not yield the concrete dependence of α on the momentum transfer, and the placement of the real resonances does not restrict in fact the behavior of near zero, i.e., nonlinearity of baryon trajectories is admissible in a very wide range.

4. BACKWARD $\pi^-n(\pi^+p)$ SCATTERING AT HIGH ENERGIES AND SINGULARITY OF THE πN-INTERACTION AMPLITUDE NEAR ZERO. ANALYSIS OF THE DATA AT LOW ENERGIES.

Are there any additional arguments (theoretical, outside the framework of the theory of complex angular momenta, or experimental, besides backward scattering), from which conclusions can be drawn concerning the behavior of baryon trajectories?

It might seem that the answer is contained in the dual models (the Veneziano model[25]), where the trajectories should be *linear* and degenerate in spin and in parity. The predictions of the dual models are apparently satisfied for processes with meson-trajectory exchange (the meson trajectories are linear, similar, and degenerate; the proximity of the ρ and ω masses, coincidence of the trajectories of ρ and ω (of negative signature) and of A_2 and f (of positive signature), etc.). It is universally

5)We chose $\alpha_{N_\alpha}(0) = 0.5$ not by accident, for at this value $d\sigma/d\Omega = \text{const}$ and $d\sigma/du \propto E^{-1}$, i.e., the energy dependence of the scattering is the same as expected for the standing nucleon pole (see below). In fact, however, the nucleon singularity moves but the trajectory is nonlinear.

6)We shall not stop here to explain the singularities in the angular distribution of the π^+p scattering (a very strongly pronounced fact, at least from the experimental point of view). In the present theory it can be relatively easily explained also with the aid of the so called false zeros in the π^+p amplitude[23] or, in a more "natural" manner, by taking rescattering into account.[24] It can also be explained by the method described above. Because of this variety of explanations, we do not know at all the true nature of this surprising phenomenon, and the theory turns out to be so "flexible" that its predicting ability is close to zero (at least in this case).

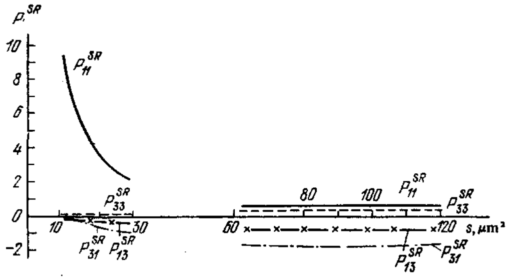

FIG. 11. P-partial waves of the "short-range" part of the πN interaction.

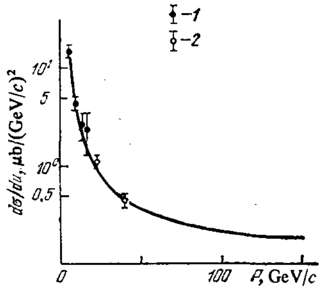

FIG. 13. Description of backward $\pi^+p(\pi^-n)$ scattering in the model[28] with $\alpha = 1$. 1) Cornell–Brookhaven, 1968. 2) ITEP, 1972.

admitted (see, e.g., [26]), however, that the principal relations of the dual models are *not satisfied* when the processes are described by *baryon* exchanges. This discrepancy between duality and the processes with baryon exchanges illustrates eloquently the profound difference between pions and baryons. It is possible that this difference is due to the fact that the pions and the baryons satisfy different statistics. Thus, dual models do not yield any information on the behavior of the baryon trajectories.

We turn now to the analysis of the experimental data. It turns out that some information on the behavior of baryon trajectories, more accurately of backward πN scattering at high energies, can be obtained by an entirely different method, namely from a phase shift analysis of experiments on πN scattering at low energies.

Elvekjaer[27] has carried out a thorough phenomenological investigation of πN ($l = 1$) partial waves near $s = 0$. This analysis has led to an exceedingly interesting result, namely an indication that there exists a strong "short-range" πN interaction localized near $s = 0$. This interaction manifested itself in the 1/2 isotropic channel. The corresponding partial wave P_{11}^{SR} (P waves are designated in the form $P_{2I,2J}^{SR}$, where I is the isospin, J is the total spin, SR is the index of the short-range action) exhibited an unexpected rise as s approached zero and became larger by an order of magnitude than the remaining P waves (Fig. 11).

It turns out that the behavior of the "short-range" πN amplitude near $s = 0$ can be connected with the asymptotic behavior of the backward πN scattering. As shown in[28], the effective value of $\alpha(0)$, which determines the backward scattering at high energies, is critical for the behavior of the partial wave near $s = 0$. If we use the Regge model[21] with N_α and N_γ *linear* trajectories (2.7) for the description of the backward πN scattering, then the corresponding partial wave does not agree at all with the behavior of P_{11}^{SR} observed at low energies (Fig. 12). Linear trajectories yield too low a value for the effective value of $\alpha_N(0)$ (the nucleon reggeon).

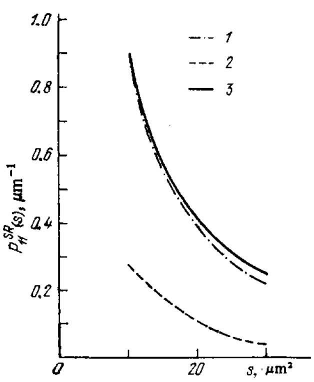

FIG. 12. P_{11}^{SR} partial wave. 1) Behavior determined from a phase shift analysis of the data at low energies; 2) wave calculated by the Regge model[21] of backward πN scattering with linear baryon trajectory; 3) calculated by the model of [28] of backward πN scattering with $\alpha = 1$.

Dew and Tschang[28] have found by analysis the value of α that can satisfy simultaneously the experimental ITEP data[22] on backward $\pi^- n$ scattering and the behavior of the partial P_{11}^{SR} wave near $s = 0$, and obtained a good description of all the data (Figs. 12 and 13) at the value $\alpha = +1$ and at positive signature. This is an unexpected result! It means that the behavior of the baryon trajectory is pomeron-like.[7)]

A similar model was proposed earlier by Ginzburg and Perlovskiĭ.[29] In their model, besides the Regge amplitudes, they considered exchange of an "elementary" nucleon in the backward $\pi^- n$ scattering process. The elementary nucleon can have a "standing" singularity, $\alpha = 1/2$. The model described satisfactorily the data of[22] on $\pi^- n$ backward scattering in the Serpukhov accelerator energy interval.

Let us formulate the main conclusions of the present chapter.

1) The ITEP experimental data[22] indicate that the strong decrease of the backward $\pi^+p(\pi^-n)$ backward scattering with energy, observed at intermediate energies ≤ 17 GeV, slows down in the energy interval 20–40 GeV.

2) An analysis of the data of the πN scattering at low energies (phase-shift analysis) points to the existence of a strong short-range interaction near $s = 0$, which manifests itself in the P_{11}^{SR} partial wave.[27]

[7)]Dew and Tschang believe that their result points to a "non-Regge" behavior of the backward scattering amplitude, taking "Regge" behavior to imply a model with linear trajectories. However, the Regge theory itself does not postulate linear trajectories and, as we have shown above, the real positions of the particles and resonances admit of trajectories having so large a nonlinearity that α can assume values all the way to $+1$.

3) The two phenomena turn out to be related (by the dispersion relations), and to explain them it is necessary that the effective value of α be much larger than that obtained from linear baryon trajectories. Models with large effective value of α_N ($\approx 1/2-1$)[28,29] describe satisfactorily both the $\pi^- n$ data on backward scattering at high energies[22] and the behavior of the P_{11}^{SR} partial wave near $s=0$.[27]

4) The indicated phenomena as well as the considered theoretical models have a bearing on the singularities that manifest themselves in the crossing channel with an exchange characterized by the quantum numbers of the nucleon ($I=1/2$, $J=1/2$, $\sigma=+1$). However, there are no indications that some changes should take place in the 3/2 isotopic channel which is associated with the trajectory.

In connection with the last remark, it is very important to ascertain experimentally a picture of backward-scattering at high energies π^- mesons by protons—a reaction characterized by pure Δ exchange. Such measurements were recently performed by an ITEP group with the Serpukhov accelerator.[30]

5. BACKWARD $\pi^- p$ SCATTERING IN THE SERPUKHOV ACCELERATOR ENERGY INTERVAL. THE "GLORY" EFFECT.

The ITEP experimental setup for backward $\pi^- p$ scattering[30] is shown in Fig. 14. A 70-cm target was used with solid hydrogen cooled by liquid helium. The trajectories of the pions of the primary beam and of the scattered protons were determined with hybrid wire spark chambers. The hybrid chambers had a much better temporal resolution (≈ 100 nsec) than ordinary spark chambers (≈ 1 μsec). This made it possible to use a beam intensity $\approx 2\times 10^6$ particles per accelerator cycle. The magnetic spectrometer with the wire spark chambers made possible a momentum analysis of the forward scattered particles. A 12-meter Cerenkov counter in the "proton" arm of the spectrometer excluded events with forward-scattered pions and kaons. The backward scattered pions were registered in wire spark chambers and scintillation hodoscopes.

The measurements were performed at two energies, 24.7 and 37.8 GeV.

Figure 15 shows the differential cross sections of the backward $\pi^- p$ scattering. If the obtained cross sections are described by a simple exponential relation

$$\frac{d\sigma}{du}=\left(\frac{d\sigma}{du}\right)_{u=0}e^{Bu}, \tag{5.1}$$

then we obtain for $(d\sigma/du)_{u=0}$ and for the slope parameters B the following values:

$$\begin{aligned}&\left(\frac{d\sigma}{du}\right)_{u=0}=262\pm 37\ \text{nb/(GeV/}c)^2,\\ &\qquad B=23\pm 8\ (\text{GeV/}c)^{-2}\ \text{at}\quad E=24.7\ \text{GeV},\\ &\left(\frac{d\sigma}{du}\right)_{u=0}=160\pm 22\ \text{nb/(GeV/}c)^2,\\ &\qquad B=19\pm 5\ (\text{GeV/}c)^{-2}\ \text{at}\quad E=37.8\ \text{GeV}.\end{aligned} \tag{5.2}$$

Figure 16 shows the energy dependence of $(d\sigma/du)_{u=0}$. For comparison, the $\pi^- p$ data are shown at lower energies,[18,19] as well as the $\pi^+ p$ and $\pi^- n$ data.[18,22] As seen from Fig. 16, the behavior of the backward $\pi^- p$ scattering cross section exhibits no singularities whatever when the energy is varied. The new $\pi^- p$ data[30] are continuations of the energy dependence observed at lower energies. If we assume a power-law dependence of the cross section $(d\sigma/du)_{u=0}$ on the energy, then all the backward $\pi^- p$ scattering data correspond to the relation

$$\left(\frac{d\sigma}{du}\right)_{u=0}\approx E^{-n},\quad \text{where}\ n\approx 2.0. \tag{5.3}$$

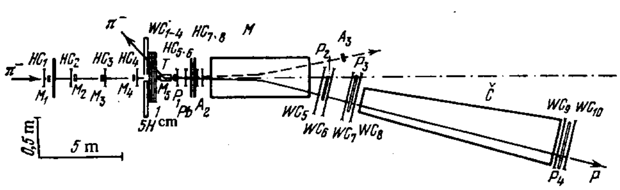

FIG. 14. ITEP experimental setup (1976). M_{1-5}—monitor counters, A_{1-3}—anticoincidence counters, P_{1-4}—counters above the "proton" branch of the spectrometer, $H_{1,2}$—hodoscopes for the registration of the backward scattered protons, HC_{1-8}—hybrid spark chambers, WC_{1-10}—wire spark chambers, C—Cerenkov counter.

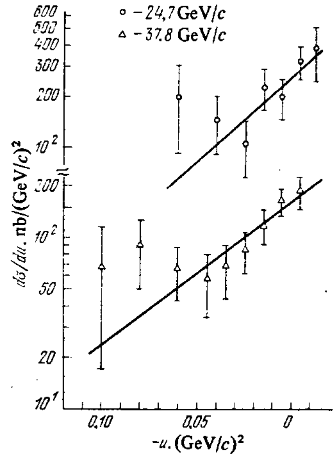

FIG. 15. Differential cross section of backward $\pi^- p$ scattering at momenta 24.7 and 37.8 GeV.

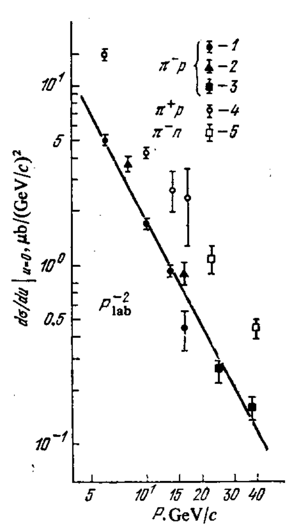

FIG. 16. Momentum dependence of the cross sections $(d\sigma/du)_{u=0}$ of backward $\pi^- p$ and $\pi^+ p(\pi^- n)$ scattering. 1) Cornell–Brookhaven, 1968; 2) Brookhaven–Carnegie–Mellon, 1968; 3) ITEP, 1976; 4) Cornell–Brookhaven, 1968; 5) ITEP, 1972.

This exponent corresponds to an effective value $\alpha_\Delta(0) \approx 0.0$.

As already mentioned, Regge models of backward scattering with linear trajectories predicted a steeper energy dependence for π^+p scattering, and this should have led to an intersection of the π^+p and π^-p cross sections in the 35 GeV region.[21] It is seen from Fig. 16 that the cross sections of the backward $\pi^+p(\pi^-n)$ and π^-p scattering not only fail to intersect in the investigated energy region, but have even no tendency to approach one another.

Attention is called to the fact that at Serpukhov energies the π^-p data show a very sharp increase of the cross section with increasing angle as 180° is approached (backward peak). The peak slopes (5.2) (see Fig. 15) are much larger than at lower energies (see Fig. 2). To be sure, the slopes (5.2) were determined in the region of very small values of u ($|u| \leqslant 0.06$ (GeV/c)^2 for $E = 24.7$ GeV and $|u| \leqslant 0.1$ (GeV/c)^2 for $E = 37.8$ GeV), whereas at lower energies the cross sections were not investigated at such small values of u, and the slopes were determined over a wider interval ($|u| < 1$ (GeV/c)^2 (see Fig. 2)). In the Serpukhov energy interval, on the other hand, the slopes of the peaks of the backward π^-p and π^-n scattering turn out to be close to each other (cf. Figs. 8 and 15).

The proximity of the slopes of the backward π^-p and π^-n scattering peaks suggests an analogy with geometrical optics. Some problems concerning the interaction of nuclear and elementary particles were considered in[31] from the point of view of optical effects of scattering of light by an extended object (a raindrop). In particular, backward scattering was interpreted in that paper as an effect analogous to glory in optics (backward scattering of sunlight by a raindrop). This beautiful optical phenomenon can be observed by standing on a mountain top and facing a cloud with the sun in the back. Glory is a bright halo around the shadow cast on the cloud by the observer's head. The light in glory is produced by backward scattering within a very narrow cone, such that even though a person can see on the cloud his own shadow as well as the shadows of his companions, he can see the glory only around his own head.

The woodsman winding westward up the glen
At wintry dawn, where o'er the sheep-track's maze
The viewless snow-mist weaves a glistening haze
Sees full before him, gliding without tread
An image with a glory round its head;
The enamoured rustic worships its fair hues,
Nor knows he makes the shadow he pursues.

(S. T. Coleridge (1772–1834)
Constancy to an Ideal Object)

Glory is a long-known effect (1735), but until recently attempts at a quantitative description of this phenomenon were not successful. The usual calculation of the diffraction of backward-scattered light from a raindrop leads to excessively small values of the intensity. The phenomenon was understood only recently.[32] The glory mechanism consists of resonant excitation of so called surface waves. This takes place when the radiation wavelength is commensurate with the dimension of the object.

The same interval $kR \sim 10$–200, where k is the wave vector and R is the dimension of the object, corresponds to the following:

a) scattering of light $\lambda = 2\pi/k = 4000$–5000 Å by a raindrop of dimension 0.001–0.01 mm;

b) scattering of nuclei with 100 MeV/$c \lesssim k \lesssim 6$ GeV/c by nuclei with dimension ≈ 6 F;

c) scattering of elementary particles with 2 GeV/c $\lesssim k_{\rm cms} \lesssim 40$ GeV/c (the interval covered by modern accelerators, including colliding beams), with dimension 1 F $= 10^{-12}$ mm.

In the model of[31], backward scattering should be diffractive:

$$\left.\frac{d\sigma}{dt}\right|_{\theta\approx\pi} \propto [J_0((\pi-\theta)\,kR)]^2, \qquad (5.4)$$

where J_0 is a Bessel function, which has a maximum at $\theta = \pi$ and oscillations with zeros fixed by the argument $(\pi - \theta)k$ (corresponding to $\approx \sqrt{-u}$ in the language of particle physics).

This behavior of backward scattering was observed

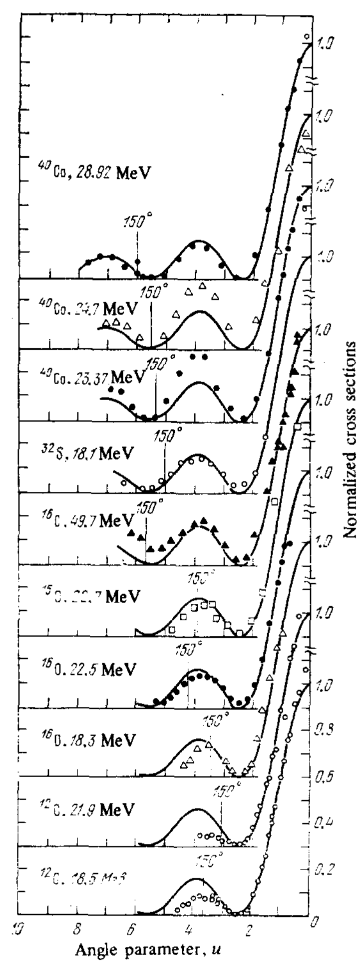

FIG. 17. Backward scattering of α particles from nuclei. Curve—model of[31].

in nuclear physics[33] in the case of elastic backward scattering of α particles by nuclei. Figure 17 shows three zeros of the Bessel function.

A similar picture (in the model of[31]) should take place also in backward scattering of elementary particles at high energies. Thus, the known minimum (dip) in the backward π^+p scattering cross section at $u = 0.16$ $(\text{GeV}/c)^2$ (Fig. 2) corresponds to the first zero of the Bessel function $J_0(R\sqrt{-u})$. From this point of view, the angular characteristics of backward scattering in π^+p and π^-p reactions should be similar, and the narrow peak in the backward π^-p scattering, obtained from the data of ITEP[30] at Serpukhov energies, can serve as an argument in favor of such a "geometrical" approach to the problem of backward scattering.

6. CONCLUSION. RADIATIVE CORRECTIONS TO BACKWARD SCATTERING.

Can we state that the investigation of the backward scattering of pions by nucleons at high energies have revealed strong short-range forces that manifest themselves in nucleon exchange or (and) the picture in backward scattering has a diffraction character (a narrow peak in the backward π^-p scattering)? Of course not. At best we can only suspect that "something of interest" takes place in the πN interaction, as is possible indicated by the data on backward πN scattering[22,30] at the energies of the Serpukhov accelerator. These data were obtained in a single laboratory, and must be confirmed by other groups and at higher energies (say, in Batavia). However, the investigation of backward scattering at high energies meets with a fundamental difficulty. In backward scattering of a charged particle (say in the π^-p reaction) the electric charge is subjected to tremendous accelerations (is turned backwards as a result of the scattering). This "jolt" leads to intense emission of radiation. Since emission of a radiative γ photon upsets the elastic kinematics of the scattering, the resultant correction depends both on the actual form of the experimental setup (the stronger the criterion for separating the elastic kinematics, the larger the correction), and on the energy (the correction is larger at higher energies). Radiative corrections in pion scattering were calculated by Sogord.[34] According to Sogord, radiative corrections to backward π^-p scattering in the region $u \approx 0$ are respectively, 10, 40, and 110% at 2, 20, and 200 GeV. Allowance for the radiative corrections for the interacting hadrons at so large a value of the corrections is a difficult task; it may be necessary to determine the corrections experimentally (by registration of the γ photons). However, the motivation for the investigation of backward scattering at high energies is sufficient to justify these efforts.

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