This constnnt turns out to be quite large,[7] $c_{NN\to NN} \approx 4$, so that at energies up to $E_{lab} \approx 50-100$ BeV the cross sections of the elastic and inelastic processes that proceed through the annihilation channel via the "quasi-vacuum" states are practically constant.

The experimental data on NN scattering[5] show, in accord with the statement made above, that in the range 10—27 BeV there is a noticeable cross section for the production of the $D_{3/2}$ and $F_{5/2}$ resonances. No $P_{3/2}$ resonance with isotopic spin $T = 3/2$ is seen to be created here, a fact attributed in our theory to the lack of "quasi-vacuum" states in the annihilation channel for this process. If we do not assume this agreement between theory and experiment to be accidental, it serves as an argument in favor of assuming that modification of the Mandelstam representation in anomalous cases is of no significance in the given scheme.

In this connection, we note a circumstance of importance from the experimental point of view. Since the cross sections for the creation of resonant states in processes proceeding via the annihilation channel through the quasi-vacuum states do not decrease in practice with increasing energy, it becomes possible to search for these resonances in reactions at higher energies. It is obvious that such resonances will be created effectively both in forward and in backward scattering.

3. Let us consider the scattering of nucleons by nuclei. We assume that in the anomalous cases when all the particles involved are stable in spite of the modification of the Mandelstam representation, the behavior of the amplitudes at high energies is determined by the extreme right-hand pole in the l-plane and, in addition, relation (5) holds true.

One of the consequences of this assumption is the following relation between the total cross sections σ_{NA}, σ_{NN}, and σ_{AA} (nucleon-nucleus, nucleon-nucleon, and nucleus-nucleus, respectively) at high energies:

$$\sigma_{NN}\sigma_{AA} = \sigma_{NA}^2. \tag{8}$$

The usual dependence of the cross section on the atomic number, $\sigma_{NA} \sim A^{2/3}$ and $\sigma_{AA} \sim A^{2/3}$, does not satisfy this relation. This may be physically due to the fact that in this theory the radius of the nucleon increases logarithmically with increasing energy, and becomes greater than the nuclear radius at sufficiently high energy.

One cannot exclude the possibility of having $\sigma_{NA} \sim A$ and $\sigma_{AA} \sim A^2$, which does not contradict relation (8) within the framework of the physical picture at high energies (this idea is due to I. Yu. Kobzarev). The energies above which the relation $\sigma_{NA} \sim A^{2/3}$ is violated are difficult to estimate at the present time.

Note added in proof (May 3, 1962). At high energies, the resonances $D_{3/2}$ and $F_{5/2}$ should arise effectively in both NN-scattering and πN-scattering. As follows from (5), the ratio of the differential cross sections for the creation of such a resonance in NN and πN scattering is equal to the ratio of the differential cross sections of elastic NN and πN scattering:

$$d\sigma_{NN\to NN^*}(s, t)/d\sigma_{\pi N\to\pi N^*}(s, t) = d\sigma_{NN\to NN}(s, t)/d\sigma_{\pi N\to\pi N}(s, t).$$

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PROBABILITY OF THE $\pi^+ \to \pi^0 + e^+ + \nu$ AND $\pi^+ \to \gamma + e^+ + \nu$ DECAY

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THE study of the β decay of the π meson

$$\pi^+ \to \pi^0 + e^+ + \nu \tag{1}$$

permits us to determine directly whether the vector current is conserved in weak interactions.[1] The present interest in this process, which was first predicted by Zel'dovich[2] as long ago as in (1954), is extremely great since it tests one of the basic assumptions forming the foundation of the contemporary theory of weak interactions. Unfortunately, the experimental study of the β decay of the π meson encounters very great difficulties, since the probability is vanishingly small; according to the universal theory,[1,3] the relative probability is $\lambda = \omega(\pi^+ \rightarrow \pi^0 + e^+ + \nu)/\omega(\pi^+ \rightarrow \mu^+ + \nu) = 1.03 \times 10^{-8}$.

In a previous paper,[4] we have obtained the first experimental information on the β decay of the π^+ meson, which confirms the theoretical prediction of a very small value of λ, for which a limiting value $\pi < 7 \times 10^{-8}$ was found. This article reports the results of new investigations of the β decay of π^+ mesons, carried out using improved apparatus with an efficiency several times higher than before.[4] In carrying out these investigations, we have also obtained information on the radiative π-meson decay

$$\pi^+ \rightarrow \gamma + e^+ + \nu \qquad (2)$$

which is also of interest in connection with the hypothesis of the vector current conservation.[5]

The experimental method carried out is basically the same as that described in [4]. π^+ mesons traversed a system of scintillation counters and slowing-down absorbers and stopped in the scintillator of the target counter. For the detection of the two oppositely directed gammas from the π^0 decay, we have used total absorption Cerenkov spectrometers. Only the electronic circuitry has been considerably changed. In the present experiment, it consisted of two fast coincidence circuits, one with a resolving time of 2×10^{-9} sec for the detection of the stopping π mesons, using the method of "stopping detectors."[6] The second basic coincidence circuit served for the detection of delayed coincidences between the two spectrometers and the counter placed in the π-meson beam. Signals from the fast-coincidence circuits were fed to the output slow-coincidence circuit.

The recording apparatus was tested and calibrated using a beam of negative π mesons. A vessel with liquid hydrogen was placed, instead of the target counter, between the spectrometers, and the γ quanta from the decay of π^0 mesons produced in the reaction $\pi^- + p \rightarrow \pi^0 + n$, which occurs when the π^- mesons stop in the hydrogen, were detected. The main characteristic of the detection system thus obtained, i.e., the curve of the delayed coincidences between the counter placed in the π-meson beam and the two spectrometers (called gates), is shown in Fig. 1. As can be seen from the figure, the gates are sufficiently wide (40×10^{-9} sec) to detect efficiently the π^+-meson β decay whose characteristic time is 25.6 $\times 10^{-9}$ sec. Moreover, the apparatus ensured a high resolving power of the coincidences between the spectrometers (3×10^{-9} sec). The full efficiency of the system for the detection of the β decay of π^+ mesons was also determined using the π^- meson beam, and was found to be equal to 8%. With the stopping π^+ mesons having an intensity 1.2×10^4 sec^{-1}, we should therefore expect that, in the absence of a background, the mean rate of detection should equal one in 20 hours.

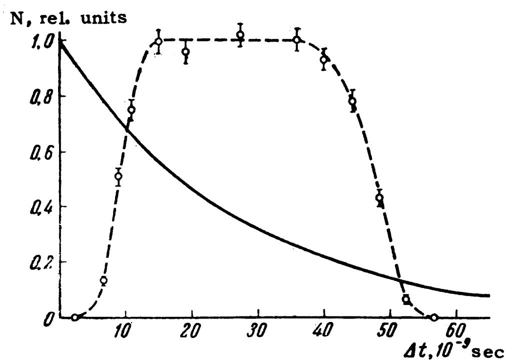

FIG. 1. Time gate for the delayed coincidences. Δt – delay between the counters determining the moment when π^- mesons stopped in hydrogen, and the spectrometers detecting the γ rays from the π^0 decay: N – counting rate of the coincidences. Solid curve – exponential function with exponent equal to the lifetime of π^+ mesons.

The main measurements with the π^+ meson beam took about 30 hours, during which 2×10^9 π^+ mesons traversed the setup. During that time, two counts of the output coincidence system were recorded. In the absence of background, this corresponds (in units of λ) to $\lambda_r = 2.1 \times 10^{-8}$. In order to determine the background, a control experiment was carried out during which an additional delay of the signals from the scintillation counters to the coincidence circuit was introduced (see Fig. 2). As a preliminary stage, a study of the temporal beam structure was carried out by the method of chance coincidences which showed that the structure has a well defined periodic character (Fig. 2). The value of the delay was chosen to be equal to the first period of the temporal structure of the beam (76×10^{-9} sec), which guaranteed that the background conditions in the control and main experiment were identical, apart from a small contribution from the charge-exchange of π mesons in flight, which was determined in a separate experiment. The detection efficiency of the π^+-

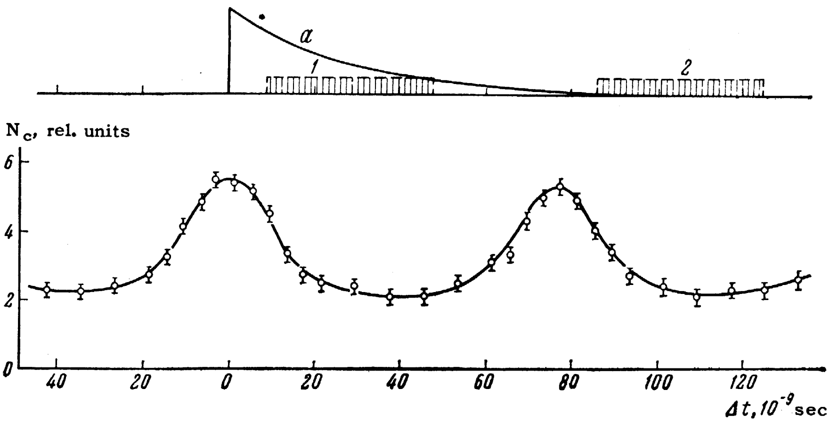

FIG. 2. Temporal structure of the π^+ meson beam. N_c is the counting rate of chance coincidences as a function of the delay Δt between two counters placed in the beam. The upper diagram indicates a typical position of the gate during the main (1) and background (2) experiments; a – exponential decay curve.

meson β decay was lowered by a factor of 20 times because of the introduction of the delay. In carrying out the background measurements, two counts were detected which corresponded to a mean background level $\lambda_b = 3.4 \times 10^{-8}$, taking into account the contribution from the π^+-meson charge exchange in flight, which amounted to 0.2×10^{-8}.

Using the experimentally obtained values of λ_r and λ_b, we can find the integral distribution function $W(\lambda > \lambda_m)$ for the relative probability λ. In our case, it is given by the formula

$$W(\lambda > \lambda_m) = \int\limits_{2\lambda_m/\lambda_r}^{\infty} e^{-\eta} d\eta \int\limits_{0}^{\infty} \frac{(\eta + k\xi)^2 \xi^2}{2(2 + 2k\xi + k^2\xi^2)} e^{-\xi} d\xi, \quad (3)$$

where $k = \lambda_b/\lambda_r$. The function $W(\lambda > \lambda_m)$ is shown in Fig. 3. It was found to be close to an exponential function with exponent 1.5×10^{-8}. This value of the exponent represents a limiting estimate for the relative probability of the β decay of the π^+ meson (at the 1/e level):

$$\omega(\pi^+ \rightarrow \pi^0 + e^+ + \nu)/\omega(\pi^+ \rightarrow \mu^+ + \nu) < 1{,}5 \cdot 10^{-8}.$$

The above estimate is very close to the value predicted by the universal theory,[1,3] and corroborates the hypothesis of vector current conservation, although it does not prove it (since, in the case of nonconservation of the vector current, the probability of β-decay of the π^+ meson could also be substantially greater). The estimates given above enable us to find an upper limit for the constant G which determines the intensity of the β decay of the π^+ meson:

$$G < 1{,}2 G_\beta.$$

where $G_\beta = 1.40 \times 10^{-49}$ erg-cm^3 is the vector constant of the nuclear β decay.[1] The distribution function of G is shown in Fig. 3.

As was shown by Bludman and Young,[5] the study of the radiative decay of the π meson (Eq. 2) can yield definite information concerning

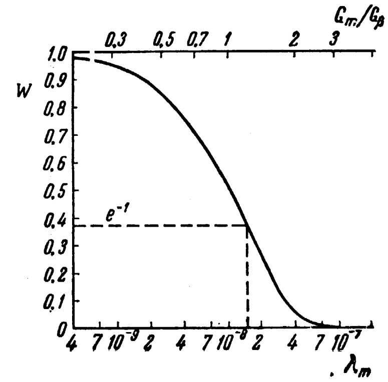

FIG. 3. Integral probabilities $W(\lambda > \lambda_m)$ and $W(G > G_m)$.

the conservation of the vector current. For this purpose, it is necessary to study the relatively rare decay events in which the angle θ between the positron and the γ ray is close to 180°. It is then possible to separate experimentally the most interesting structure-dependent[5] part of the radiative decay, which is not related to the usual bremsstrahlung but occurs as a result of virtual strong interactions in the decay process. In the case where the vector current is conserved, the probability of the structure-dependent radiative decay can be calculated; however, the predictions of the theory are not as definite as in the case of the β decay of the π meson.

The arrangement used in the present experiment enabled us to detect the radiative decay of π^+ mesons in conditions ensuring an efficient separation of the structure-dependent parts (θ = 180°, high-energy threshold of the spectrometers). The measurement carried out enabled us to give a limiting estimate for the differential probability of the radiative decay

$$\left[\frac{d\omega(\pi^+ \rightarrow \gamma + e^+ + \nu)}{d\Omega}\right]_{\theta=180°} \Big/ \omega(\pi^+ \rightarrow \mu^+ + \nu) < 9 \cdot 10^{-8}\ \mathrm{sr}^{-1}.$$

This estimate is substantially lower than the experimental limiting estimate of 4×10^{-6} sr^{-1}

found earlier,[7,5] and is close to the 3.6×10^{-8} sr^{-1} predicted theoretically for the case of vector current conservation.[5] If we use the angular distribution calculated by Bludman and Young, then, from the data obtained by us, it follows that the total relative probability of the structure-dependent π^+-meson radiative decay, integrated over θ, for which the universal theory[5] gives the value 6×10^{-8} is limited by the inequality

$$\omega_{SD}(\pi^+ \to \gamma + e^+ + \nu) / \omega(\pi^+ \to \mu^+ + \nu) < 1.5 \cdot 10^{-7}.$$

After concluding the experiment described above, we have introduced a number of changes into the electronic circuitry, as a result of which it has been possible to improve considerably the resolution of the coincidence circuits, and to increase the selectivity of the detector of the stopping π^+ mesons. This enabled us to lower the background of chance coincidences by a factor of several times. In a series of experiments carried out with the new apparatus, it was found that the β decay of the π meson exists, and the first result for the value of its probability was confirmed. As a result of the measurement, during which the array was traversed by 0.6×10^{10} π^+ mesons, it was found that

$$\lambda = (1.1^{+1.0}_{-0.5}) \cdot 10^{-8}, \qquad G = (1.14 \pm 0.37)\, G_\beta$$

which confirms the correctness of the vector conservation hypothesis.

In conclusion, we wish to express our thanks to S. S. Gershteĭn, B. Pontecorvo, and O. V. Savchenko for helpful discussion.

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BEHAVIOR OF THE REAL PART OF THE SCATTERING AMPLITUDE AT VERY HIGH ENERGIES

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In a previous paper[1] it was shown that the Mandelstam equation allows two types of asymptotic behavior of the imaginary part of the amplitude. One type of asymptotic behavior (which is unique in that only this can lead to constant total cross section) agrees precisely with the behavior of the Regge type:[2]*

$$A_s(s,t) = f(t)\, s^{L(t)}. \tag{1}$$

If the total cross section approaches a constant as $s \to \infty$, then $L(0) = 1$, in agreement with the optical theorem. Below we will always assume that the total cross section approaches a constant: thus $A_s(s,t)$ has the form (1).

In the elastic scattering of isoscalar particles the asymptotic form of the imaginary part of the scattering amplitude in the second channel is easily obtained:

$$A_u(u, t) = f(t)\, u^{L(t)} \tag{2}$$

for $|u| \gg 1$.

With the help of (1) and (2) one can obtain the explicit form of the real part of the amplitude:

$$\operatorname{Re} A(s, t) = \frac{f(t)}{\pi}\left\{s^2 \int_4^\infty \frac{s'^{L(t)-2}}{s'-s}\, ds' + (-s)^2 \int_4^\infty \frac{u'^{L(t)-2}}{u'+s}\, du'\right\}. \tag{3}$$

In the relation (3) we have utilized the fact that if t is finite and $s \to \infty$ then $s \approx -u$. It follows from crossing symmetry that the second subtraction term (proportional to s) vanishes. The possibility of substituting the asymptotic form of the imaginary part into the dispersion relations can be easily verified: the contribution of the "nonasymptotic" region

$$s^2 \int_4^\lambda \frac{A_s(s', t)}{(s'-s)\, s'^2}\, ds' + u^2 \int_4^\lambda \frac{A_u(u', t)\, du'}{(u'-u)\, u'^2}$$

is of order O(1) (here λ is the "limit" of the region of the asymptotic behavior).

After integration one obtains from (3)

$$\operatorname{Re} A(s, t) = f(t)\, s^{L(t)} \frac{1 + \cos \pi L(t)}{\sin \pi L(t)} + O(1). \tag{4}$$