THE NEUTRAL ρ^0-MESON HYPOTHESIS IN THE LIGHT OF DATA ON ANTIPROTON ANNIHILATION

V. I. GOL'DANSKIĬ and V. M. MAKSIMENKO

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

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According to the Gell-Mann—Nishijima scheme, a neutral ρ^0 meson with zero strangeness should exist. The following decay modes for this particle have been indicated in the literature:

$$\rho^0 \to \pi^+ + \pi^- + \gamma, \quad \rho^0 = \pi_0^0 \to 2\gamma; \quad \rho^0 = \pi_{10}^0 \to 3\gamma.$$

The possible contribution of such decays (for various ρ^0-meson masses) in the annihilation of antiprotons is discussed from the viewpoint of the statistical theory of multiple processes. The data presently available on the yield of π^+, π^-, and π^0 mesons during annihilation are inconsistent with the existence of a π_0^0 meson with a mass smaller than 3.5 m_π and also with the existence of a π_{10}^0 meson with a mass smaller than 5.5 m_π. On the other hand, the $\rho^0 \to \pi^+ + \pi^- + \gamma$ decay not only does not contradict the experimental data, but even removes some difficulties connected with the determination of the interaction volume.

THE Gell-Mann—Nishijima scheme of elementary particles, both in its original form, and modified to take the conservation of the number of isofermions into account, predicts the existence of the not as yet observed neutral ρ^0 meson with isotopic spin and strangeness equal to zero. The possible properties of these mesons, and its decay modes in particular, have lately been frequently discussed in the literature.

The decay mechanism of the ρ^0 meson has been discussed in particular detail by Zel'dovich,[1] who used the most widely-accepted assumption that this meson is a pseudo-scalar particle with zero spin similar to a nucleon-antinucleon pair in the $0^{S\,1}S_0$ state (according to the Bethe-Hamilton scheme[2]). In such a case, the most probable decay mode of the ρ^0 meson with a mass greater than the double mass of the π meson is the decay

$$\rho^0 \to \pi^+ + \pi^- + \gamma. \tag{1}$$

This decay is predominant also for $m_\rho > 3m_\pi$ and even for $m_\rho \gtrsim 4m_\pi$, since the 3π decay is forbidden, and the 4π decay (as are the decays into a greater number of π mesons) is strongly suppressed by the necessity of large orbital momenta in the final state.

For $m_\rho < 2m_\pi$, the predominant decay mode should be

$$\rho^0 \to 2\gamma. \tag{2}$$

Purely hypothetical variants of ρ^0 mesons are the "twin" of the usual π^0 meson, the so-called π_0^0 meson,[3] and also a particle close in mass to the π^0 meson having unit spin, the π_{10}^0 meson.[4] The proposed basic decay schemes of these particles are as follows:

$$\pi_0^0 \to 2\gamma, \tag{2'}$$

$$\pi_{10}^0 \to 3\gamma. \tag{3}$$

We shall not dwell on a description of all the attempts to find the ρ^0 meson and, in particular, the π_0^0 and π_{10}^0 mesons (see references 4—9), but, instead, we shall analyze those data that can now be deduced from experiments on antiproton annihilation.

The latest data on the annihilation of antiprotons stopping in hydrogen[10] reveal that π^+ and π^- mesons carry away $\frac{2}{3}(\pm 3\%)$ of the released energy, and π^0 mesons about $\frac{1}{3}$. Since the yield of π^0 mesons is determined from their decay γ rays, we can assume that, from the equality of the π^+, π^-, and π^0 meson yields, we can deduce the presence of one γ ray for each such meson. Therefore, the production of ρ^0 mesons having the decay mode (1) would correspond to a certain decrease of the γ-ray yield, while the production of ρ^0 mesons having a decay mode (2), or even more so (3), would lead to an increase in the γ-ray yield.

In view of the limitation stated above, we shall not discuss here the ratio of yields of π^+, π^-, and π^0 mesons in multimeson decays of heavy ρ^0

mesons ($m_\rho > 4m_\pi$). The corresponding relations can be obtained from the selection rules for the isotopic spin. It is clear, however, that the closer the mass of the ρ^0 meson to the maximum possible one (i.e., the mass of two nucleons), the smaller will, in general, be the role of the intermediate state in the possible variations of the relative yield of mesons of various signs.

Thus, we will consider three decay modes, types (1), (2), and (3):

$$\rho^0 \to \pi^+ + \pi^- + \gamma, \quad \rho^0 \to 2\gamma, \quad \rho^0 \to 3\gamma$$

and we shall compare the possible contribution of these processes to the yield of γ rays in the annihilation of antiprotons with the experimental data. In doing so, it is more convenient not to use the energy fractions of $\pi^\pm$ and π^0 mesons given above, but rather their average number per act of annihilation:[10]

$$\bar{n}_{\pi^+} = 1.53 \pm 0.08, \quad \bar{n}_{\pi^-} = 1.53 \pm 0.08, \quad \bar{n}_{\pi^0} = 1.60 \pm 0.50.$$

We shall assume, that, together with π^+, π^-, and π^0 mesons, ρ^0 mesons may be produced in the annihilation of antiprotons. In order to estimate their yield, we shall use the statistical theory of multiple production, assuming that the interaction strength for π^+ and ρ^0 mesons is the same, and, therefore, that the relative yield of ρ^0 mesons depends only on their mass, of which different values are used for the calculation.

The total number of emitted π^+ and π^- mesons is assumed to be given as $\bar{n}_{\pi\pm} = 3.06 \pm 0.12$, and, for different assumptions with respect to the ρ^0 mass, the number of half of the emitted γ rays, $n_\gamma/2$, is calculated. It is evident that, for the decay mode (1), the quantity $n_\gamma/2$ decreases with decreasing assumed mass of the ρ^0 meson, while, for the modes (2) and (3), the contrary is true.

The effective volume V in which, according to the theory, statistical equilibrium is attained between all secondary particles, is considered as an adjustable parameter, and is so chosen that the calculated value of $\bar{n}_{\pi\pm}$ for a given V is equal to the experimental one.

In order to calculate the statistical weights, the exact formulas were used.[11,12] The results of the calculations for the three decay modes are shown

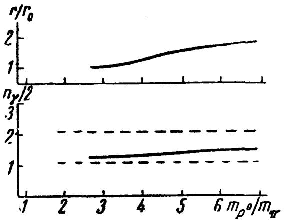

FIG. 1. Decay mode $\rho^0 \to \pi^+ + \pi^- + \gamma$.

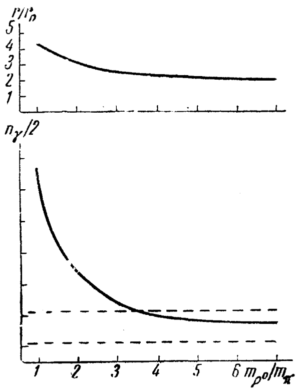

FIG. 2. Decay mode $\rho^0 \to 2\gamma$.

in Figs. 1—3. The dotted line denotes the experimental limits of the quantity $n_\gamma/2$ (equal, in the absence of ρ^0 mesons, to the number of π^0 mesons). In the upper part of the figures, the variation of the radius r of the effective volume V $= 4\pi r^3/3$ expressed in units of $r_0 = \hbar/m_\pi c$ is shown.

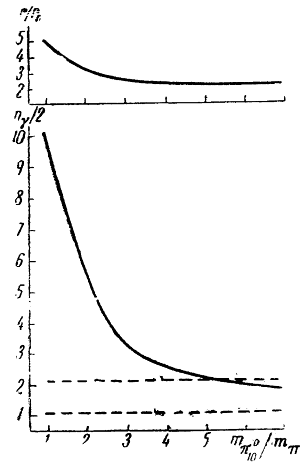

FIG. 3. Decay mode $\pi^0_{10} \to 3\gamma$.

As can be seen from Fig. 1, mode (1) does not contradict the experimental data (because of their low accuracy) for any value of the ρ^0-meson mass. The decay mode (2) (Fig. 2) would lead to a disagreement with the experiment, except for $m_\rho \geq 3.5\ m_\pi$. The decay mode (3) (Fig. 3) could be consistent with the available data only for the case of a very heavy ρ^0 meson with a mass not less than 5.5 π meson masses.

Thus, one can assume that the yield of mesons of various signs in antiproton annihilation definitely contradicts the existence both of π^0_0 mesons and, even more so, of π^0_{10} mesons.

It is interesting to note that, for the decay mode (1), one can obtain a better agreement between the calculation and the experiment for $r = r_0$. As is well known,[12] for such a value of r, the theory is in good agreement with the data on NN- and πN-collisions, but, for the case of annihilation, the calculated number of π^0 mesons produced is underestimated by not taking the decay mode (1) into account, and it is found that it is necessary either to increase r, or to introduce additional assumptions.

In our calculations, we did not take the hypothetical resonance interaction of π mesons into account,[13,14] and also did not use the variant of statistical theory with the Lorentz-invariant phase volume[15] (see also reference 10). However, both in this and in the other case, the fraction of ρ^0 mesons will be smaller than in the estimates obtained above, which would tend to lessen any contradiction with the experiment.

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151