

SUPPRESSION OF TWO-MESON ANNIHILATION IN ANTIPROTON-PROTON INTERACTION

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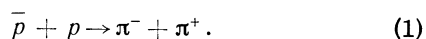
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It is demonstrated that the suggestions made by various authors to explain the suppression of the $p + \bar{p} \rightarrow \pi^- + \pi^+$ reaction can be distinguished experimentally. Annihilation involving the emission of K mesons is examined from the viewpoint of the various proposals and corresponding experiments are suggested.

ONE of the most interesting experimental facts is the suppression of the two-meson annihilation in the antiproton-proton interaction. Among 3000 annihilation stars in a propane bubble chamber (antiproton momentum ~ 1 Bev/c) Goldhaber et al. (cited in Sakurai¹) did not observe a single two-meson annihilation event (see Sakurai,¹ p. 29).

In the studies of annihilation of antiprotons with momentum up to 1.15 Bev/c in a hydrogen bubble chamber² altogether only two events were found, that the authors could interpret as the reaction



At that an estimate of 1/400 was given for the upper limit of the relative probability of this process. This number is significantly smaller than estimates made on the basis of various versions of the statistical theory which gives good agreement with experiment for the average multiplicity of pions in annihilation. According to these estimates the two-meson annihilation should amount to 2–10%.³⁻⁷ Nevertheless the possibility that the suppression of the two-meson annihilation could be explained within the framework of some version of the statistical theory cannot be excluded (see, for example, Desai⁸).

Various assumptions regarding the character of the annihilation process have been made in order to explain the above mentioned experimental fact. Thus, for example, Okonov⁹ suggested that the annihilation proceeds mainly through the singlet state of the $\bar{p}p$ system, for which the two-meson transition is forbidden by existing selection rules. He proposed experiments in which three-meson annihilations would be studied with the aim of establishing the presence or absence of a dependence on the spin (and isospin) state of the $\bar{p}p$ system

of the annihilation transition matrix.* Sakurai¹ suggested that the annihilation proceeds through intermediate bosons, each of which rapidly decays into two or three pions. Since in the annihilation act on a free nucleon at least two such bosons should be emitted two-mesonic (and also three-mesonic) annihilations would be suppressed.† Finally, Shirokov and the author¹¹ have shown that annihilation into two pions is forbidden if the charge parity of the $\bar{p}p$ system is opposite to the one that follows from Dirac's equation. The observation of two events of annihilation into $\pi^- \pi^+$ seemingly excludes this last possibility. However, if one takes into account the difficulties noted by Chamberlain,² in the identification of two-mesonic annihilation events then, apparently, the question of the forbiddenness of reaction (1) cannot be considered as definitely settled.‡

It should be noted that the study of the reactions



permits one to distinguish between the proposals here discussed. Indeed, if the suppression of reaction (1) is due to statistical factors, then reactions (2) and (3) will also be suppressed. An analogous situation would result if the annihilation proceeds through intermediate bosons, however in

*A study of this question within the framework of the Ball and Chew model shows that such a dependence should take place.¹⁰

†Annihilation into two (three) pions could arise in this case, in principle, only through virtual interactions of the intermediate bosons.

‡For example, it cannot be excluded that the events represented annihilation into π^- and π^+ with the emission of a soft photon.

that case three-meson annihilations should be suppressed to the same extent. The simultaneous suppression of reactions (1) — (3) could be caused by dominant annihilation in the singlet state of any $\bar{N}N$ system independently of isospin (and not only of the $\bar{p}p$ system). The same experimental situation arises in the case when the annihilation proceeds not only mainly through the singlet state, but basically in the state of isospin 1.* In that case, as already indicated by the author,⁹ the question about the dominance of annihilation in the 1S_0 state can be settled by studying three-meson annihilations.

If it should turn out that reaction (1) is forbidden while reactions (2) and (3) are allowed, then two of the above discussed possibilities will remain:

a) the charge parity of the $\bar{p}p$ system is opposite to the one that follows from Dirac's equation, i.e., $C_{\bar{p}p} = -1$;

b) the Dirac parity holds, but the dominance of annihilation in the singlet state is true only for the $\bar{p}p$ system (and not for $\bar{N}N$ in general). This is possible, for example, if the amplitudes for the annihilation transitions in the triplet state with isospin 0 and 1 are equal in magnitude and opposite in phase.

The versions a) and b) can be distinguished by the energy dependence of reactions (2) and (3). This is easily shown in the framework of the selection rules based on the so-called G-parity,[†] first introduced by Lee and Yang.¹² For the Dirac version of charge parity one has for the $\bar{n}p$ ($\bar{p}n$) system $G = (-1)^{l+s+1}$, and if $C_{\bar{p}p} = -1$ then $G = (-1)^{l+s}$ (l and s are the values of the orbital angular momentum and spin respectively of the $\bar{N}N$ system). When it is noted that the 2π transition of the $\bar{N}N$ system is possible only in the triplet state ($s = 1$), and that the G-parity of the $\pi\pi$ system is $+1$, then it is seen that reactions (2) and (3) are possible in version a) for odd values of orbital angular momentum (1, 3, ...), and in version b) for even values of l (0, 2, ...).

This means that in the region of not too large energies (up to $E_{\bar{p}} \sim 50$ Mev) in the version a) the cross section for reactions (2) and (3) will rise like $E^{1/2}$, and in the version b) will fall like $E^{-1/2}$. Further if the estimates of Desai¹⁰ are correct,

*In this connection it should be noted that in the Fermi-Yang model the existence of the pion indicates a strong attractive interaction between the nucleon and antinucleon in the singlet state with isospin 1.

†G-conjugation stands for the consecutive operations of charge conjugation and rotation by 180° in isospace: $G = C \exp(i\pi I_2)$.

who showed that the capture of a stopped antiprotons proceeds mainly from the S state, then the relative yield of reaction (3) will sharply increase (decrease) in going over to annihilation in flight [respectively for versions a) and b)]. Study of reaction (2) is in principle preferable, since it permits the observation of the elementary process, however from the experimental point of view it is connected with definite difficulties. Apparently it is best to observe such a process in an antiproton beam with the help of a hydrogen bubble chamber, making use of the antineutrons produced by charge exchange: $\bar{p} + p \rightarrow \bar{n} + n$. The kinematic analysis of such an event makes it possible, in principle, to determine the energy of the antineutron annihilated as a result of a subsequent interaction. In any case the probability of such a process should be no smaller, than the probability of antiproton double scattering, which was observed in a large hydrogen bubble chamber.*

As regards reaction (3) information can be deduced from already existing experimental data on the annihilation of antiprotons on deuterons. Here, however, it is necessary to select events in which the proton remaining after annihilation carries away little momentum.

All the indications are that the system K^-K^+ ($K^0\bar{K}^0$) has the same symmetry properties as the $\pi^-\pi^+$ system.¹³ Therefore, if the reaction (1) is suppressed because the annihilation proceeds predominantly through the singlet state or because of a non-Dirac charge parity of the $\bar{p}p$ state, the reaction

$$\bar{p} + p \rightarrow K + \bar{K} \quad (4)$$

will also be suppressed.†

At the same time the reactions

$$\bar{n} + p \rightarrow \bar{K}^0 + K^+, \quad (5)$$

$$\bar{p} + n \rightarrow K^- + K^0 \quad (6)$$

will, generally speaking, not be suppressed [provided, of course, that the suppression of (4) is not due to statistical factors]. Nothing more definite can be said about the behavior of reactions (5) and (6), as long as no definite information is available on the parity of the \bar{K}^0K^+ (K^-K^0) system.

An analysis of annihilation stars in a hydrogen bubble chamber failed to produce a single event that could be reliably interpreted as $\bar{p} + p \rightarrow K^-$

*Up till now ~ 200 events of double antiproton scattering were registered in a large hydrogen bubble chamber.²

†Obviously the same conclusions would follow for a Dirac parity if $C_{K\bar{K}} = -1$.

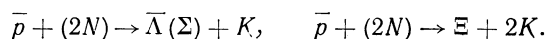
+ K^+ ; this results in an upper limit for the relative probability of this process of 0.1%.²

Among 3000 annihilation stars in propane, annihilations with production of K^- and K^+ are, apparently, also absent. Indeed, the kinematic pictures of annihilation into $\pi^-\pi^+$ and K^-K^+ are very similar. The only difference consists of slightly different values of the momenta of the π and K mesons (for annihilation at rest the momenta are 0.93 and 0.8 BeV/c respectively). Consequently, annihilations into K^-K^+ could not have been missed. It is known that in the annihilation of antiprotons on nuclei a significant number of K mesons is produced. Thus, in a propane bubble chamber the fraction of annihilation stars containing K mesons amounts to 4% at $E_p = 70$ Mev, and to more than 5% at $E_p = 500$ Mev.¹⁴

It follows from these results that the contribution of reaction (4) must be at least a 100 times smaller, as compared to other processes that lead to production of K mesons in annihilation. These processes could consist of reaction (6) or of annihilation with emission of several pions in addition to the K -meson pair; the latter process has already been observed in emulsions.¹⁵

The relative probability of the latter process, according to various versions of the statistical theory, is several times larger than the contribution of reactions (4) — (6).³⁻⁵ However, comparison with predictions of the statistical theory cannot serve as a reliable criterion for establishing the existence and degree of suppression of reaction (4). As a first step one must compare the yields of reactions (4) — (6), which should be of the same order in the absence of some factors, other than statistical, that might act to suppress reaction (4).

In those cases where the antiproton annihilates by interacting with two nucleons reactions of the following type could occur:¹⁶



A similar reaction (with emission of a Λ^0 and K^0) was recently observed in the annihilation of an antiproton on a carbon nucleus in a propane bubble chamber.¹⁷ The relative probability of such processes can be estimated from the number

of hyperons emitted in annihilation. This probability (as well as the probability for the K meson produced in the annihilation to give rise to a hyperon in the same nucleus) increases with increasing atomic weight of the nucleus. However the relative yield of K mesons from annihilations in emulsions ($A_{av} \approx 40$) and in propane bubble chambers ($A_{av} = 12$) is approximately the same ($\sim 4\%$). This makes one think that annihilation processes with the emission of hyperons do not play a decisive role.

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