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ON THE ANNIHILATION OF ANTIPROTON-PROTON SYSTEM

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Abstract

If the matrix of the annihilation transition strongly depends upon the isotopic and spin state of the antiproton-proton system, this may essentially affect the result of the annihilation.

In particular, the predominance of the $^1S_0$- state in the annihilation may lead to an increase of the average multiplicity of π mesons, whereas the preferential annihilation in the singlet state may suppress of the two-meson annihilation. The experiments are suggested to clear up as to whether there really occurs an above-mentioned dependence. The possibility is also indicated of checking experimentally whether the capture of the stopped antiproton occurs from the S-orbit in accordance with the estimates made by Day, Snow and Sucher for a K^- meson.

It has been shown/1/ that an investigation of the annihilation into 2π mesons may give some information on the intrinsic spatial and 'charge' parity of the antiproton-proton system ($\tilde{p}p$). In particular, it was pointed out, that if the charge parity of the system ($\tilde{p}p$) is opposite to that following from the Dirac equation, then the two-meson annihilation will be forbidden. So far more than 300 events of the antiproton annihilation on a proton have been recorded, while no annihilations into π^+ and π^- have been found among them/2/.

Taking into account the small statistical weight of the two-meson annihilation, it is too early to draw any conclusions basing upon this experimental material.*

Nevertheless, as was pointed out by Segre/2/, this fact is worth while noting.

In this connection it should be noted that a similar experimental situation may be also accounted for under less fundamental assumptions which do not go beyond the framework of the Dirac equation. As it has been already mentioned in discussing the available experimental data, the suppression of the reaction $\tilde{p}+p \rightarrow \pi^+ + \pi^-$ may be caused by the fact that the annihilation occurs predominantly in the singlet state of the system ($\tilde{p}p$)/4/. In this case the emission of two π mesons turns out to be forbidden (at any rate for the incident S - and P - waves) due to parity conservation and charge conjugation invariance. There is nothing unnatural in such an assumption. It is very likely, that the matrix of the annihilation transition strongly depends upon the spin and isotopic state of the system ($\tilde{p}p$)**.

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* According to different variants of the statistical theory (which give a satisfactory agreement with the experimental value of the average multiplicity of π mesons) the amount of the two-meson annihilation must amount to (3–5)%. (See e.g./3/).

** Thus, for instance, the existance of a meson within the framework of the structural model of Fermi-Yang points to the strong coupling between the nucleon and antinucleon in the singlet state with the isotopic spin $I = 1$. At the same time, similar states with spin $\sigma = 1$ are very likely to be absent, as well as the state with $\sigma = 0$ $I=0$ (the so-called 'π_0^0 meson').

In this connection it is of interest to study the relative probability of the annihilation from different states of the system ($\tilde{p}p$), esspecially, in the simplest case $\tilde{p}+$ from the S - state, in which this dependence may display itself in the most explicit form. These investigations become considerably easier, if the estimates of Day et al are found to be valid. These estimates have shown that the capture of the stopped K^- meson (or an antiproton) by a proton occurs mainly from the S - orbit /5/. The validity of this assertion, if applied to an antiproton, may be checked experimentally by studing the annihilation into two π^0-mesons. As the analysis of the selection rules shows in case of an antiproton capture from the S-state the annihilation into two π^0 mesons turn out to be forbidden. Thus, the emission two mesons in the annihilation may indicate to the admixture of higher orbital states.

In the Table are listed possible types of the annihilation transitions for the system ($\tilde{p}$ p) in the S state, in accordance with the well-known selection rules

State	Isotopic spin (I)	Spin (σ)	Parity	Charge parity	$2\pi^0$	$\pi^+\pi^-$	$3\pi^0$	$\pi^+\pi^-\pi^0$	$4\pi^0$	$\pi^+\pi^-2\pi^0$	$2\pi^+2\pi^-$
${}_1^1S_0$	0	0	−	+	☒	☒	☒	☒			
${}_3^1S_0$	0	1	−	+	☒	☒				☒	☒
${}_1^3S_1$	1	0	−	−	☒	☒	☒		☒	☒	☒
${}_3^3S_1$	1	1	−	−	☒		☒	☒	☒		

It is seen from the Table that the system $\tilde{p}p$ may transform into π^+ and π^- only from the ${}_1S$ state , so that the absence of such events in the annihilation of stopped antiprotons may imply the suppresion of this channel. The investigation of the annihilation into 3 π mesons allows to determine the relative probability of the annihilation from the ${}_3^1S_0$ and ${}_1^3S_1$ states possessing different isotopic and space spins (for other two S-states the three-meson annihilation is forbidden). If the annihilation followed the channel with $I=1$ (i.e. from the ${}_3^1S_0$-state), then a definite isotopic relation would take place

$$\frac{w(\tilde{p}+p\to\pi^{+}+\pi^{-}+\pi^{0})}{w(\tilde{p}+p\to 3\pi^{0})} = 2/3 . \qquad (1)$$

Since the transition into $3\pi^0$ from the state ${}^3_1S_1$ is forbidden by the law of 'charge' parity conservation, then the contribution of the annihilation from this state must lead to an increase of relation (1), the measurement of which allows to make quantitative estimates. The isotopic functions describing the system ($\pi^+\pi\pi^0$) as a result of the annihilation from the states ${}^1_3S_0$ and ${}^3_1S_1$ will be symmetrical and antisymmetrical with respect to the charge conjugation. This circumstance imposes definite limitations on the form of the space symmetry, since the total wave function expressed as bilinear combinations of the isotopic and coordinate functions must be symmetrical since it describes the Boze particle system. As a result, the system ($\pi^+\pi^-\pi^0$) in the state with $I=1$ will be symmetrical, whereas in the state with $I=0$ - antisymmetrical under interchange $\pi^+\leftrightarrow\pi^-$. Thus, there appears one more criterion for distinguishing the annihilation from the ${}^1_3S_0$ and ${}^3_1S_1$ - states, which allows to avoid the recording of the annihilation into $3\pi^0$-mesons what is difficult to observe.

In the first case for the half of all the annihilation events acts the momentum of π^+(π^-) meson must exceed the momentum of π^- (π^+) meson. The violation of this 'symmetry' must point to the admixture of the annihilations from the ${}^3_1S_1$ state.

If different states of the system ($\tilde{p}p$) behave differently with respect to its 'decay' into π- mesons, this may essentially affect the magnitude of the average multiplicity of π- mesons in the annihilation (N_π). Thus for example, the preferential annihilation from the ${}^1_1S_0$ state will lead to an increase of N_π since from this state the system ($\tilde{p}$ p) may decay into not less than 4π-mesons.

It is possible (though very unlikely) that this is the cause of a large multiplicity of mesons in the annihilation.

If it is really so, when we turn to higher orbital states of the system ($\tilde{p}$ p)(annihilation at high energies of $\tilde{p}$) N_π must decrease.

An investigation of the annihilation at high energies will also enable us to clear up whether the forbideness of the two meson annihilation (if any) has an absolute character or there occurs only the suppresion of this type of reaction for S (and may be for P) state, which may be accounted for without going beyond the limits of Dirac equation.

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