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ON THE REACTIONS $\bar{p} + p \rightarrow K + \bar{K} + X_0$

George A. Snow ^{*)}

CERN - Geneva

^{*)} National Science Foundation, Senior Post Doctoral Fellow
Permanent address : Physics Department, University of
Maryland, College Park, Md, U.S.A.

I. INTRODUCTION

Consider the "three" body reaction, arising from antiproton annihilations at rest in hydrogen of the type

$$\bar{p} + p \rightarrow K + \bar{K} + X_0. \quad (1)$$

X_0 can denote a neutral particle or narrow resonant state with definite quantum numbers J , P and C (spin, parity and charge conjugation quantum number). The purpose of this note is to discuss the relationship of the quantum numbers of X_0 to the characteristics of reaction (1).

We shall assume that essentially all the $(\bar{p}, p)$ annihilations at rest take place from S states. The predominance of S state capture has been suggested on theoretical grounds ^{1),2)}, and the preliminary experimental results of the CERN - Ecole Polytechnique collaboration ³⁾ on stopping antiprotons in a hydrogen bubble chamber seem to be at least qualitatively consistent with this assumption, using the test suggested by d'Espagnat ⁴⁾. In the Appendix a simple extension of d'Espagnat's argument is given so as to allow for a more quantitative analysis of experimental results.

II. SELECTION RULES

The 1S_0 and 3S_1 $(\bar{p}, p)$ states have quantum numbers $J^{PC} = 0^{-+}$ and 1^{--} respectively. Note that the second superscript in the symbol J^{PC} denotes the charge conjugation quantum number not the G conjugation quantum

2.

number as defined by Lee and Yang ⁵⁾7. It is a straightforward matter to deduce the selection rules for reaction (1) that follow from J, P and C invariance. Consider first the reaction

Experimentally it is possible to further subdivide reaction (2) into the two classes

and

Since the (K_1^0, K_1^0) and (K_1^0, K_2^0) configurations have opposite charge conjugation quantum numbers, $C = +1, -1$ respectively, different selection rules will apply for reactions (3) and (4). The allowed and forbidden reactions of type (3) and (4) are listed in Table I for $J(X^0) = 0$ and 1. Each spin value $J(X^0)$ can be associated with each of the four combinations of $(P(X^0), C(X^0)) = ++, +-, -+, --$. The symbol XX in Table I means that the reaction is forbidden by J and P conservation. The symbol X means that the reaction is forbidden only by C conservation. The symbol (ℓ, L) denotes the lowest allowed angular momentum configuration in the Dalitz-Fabri notation. ℓ is the relative orbital angular momentum of $(K^0, \bar{K}^0)$, and L is the orbital angular momentum of X^0 relative to the centre of momentum of $(K^0, \bar{K}^0)$.

TABLE I

Selection Rules for the S State Reactions $\bar{p} + p \rightarrow \bar{K}^0 + K^0 + X_0$

$J^{PC}(X^0)$	$(K_1^0 K_1^0 + K_2^0 K_2^0)$		$(K_1^0 K_2^0 + K_2^0 K_1^0)$	
	1S_0	3S_1	1S_0	3S_1
0^{++}	XX	X	XX	(1,0)
0^{+-}	XX	(0,1)	XX	X
0^{-+}	(0,0)	X	X	(1,1)
0^{--}	X	(2,2)	(1,1)	X
1^{--}	X	(0,0)	(1,1)	X
1^{-+}	(2,2)	X	X	(1,1)
1^{+-}	X	(0,1)	(1,0)	X
1^{++}	(0,1)	X	X	(1,0)

XX $\equiv$ forbidden by P and J conservation,

X $\equiv$ forbidden by C conservation only,

(ℓ, L) $\equiv$ lowest angular momentum configuration allowed.

4.

Before discussing Table I, two additional comments are pertinent :

- i) if either reaction (3) or (4) is allowed, the reaction

$$\bar{p} + p \rightarrow K^+ + K^- + X^0 \quad (5)$$

is also allowed, since $C(K^+, K^-)$ can be $+1$ or -1 ;

- ii) if X^0 is a member of an $I = 1$ charge multiplet, any reaction in Table I forbidden by C only (x), will not be forbidden for the analogous reaction involving $X^\pm$, e.g.,

$$\bar{p} + p \rightarrow K^\pm + (K^0, \bar{K}^0) + X^\pm. \quad (6)$$

III. APPLICATIONS

- A) $X_0 = A B C$ particle ⁶⁾, $J^{PC} = 0^{++}$.

Table I shows that a 0^{++} particle or state is forbidden in the $K_1^0 K_1^0 X^0$ channel, but is allowed via $K_1^0 K_2^0 X^0$. If this 2π meson state manifests itself in $(\bar{p}p)$ annihilations it should show up as an enhancement of the number of low energy $(\pi^+ \pi^-)$ configurations in the spectrum of the reactions $K_1^0 K_2^0 \pi^+ \pi^-$ or $K^+ K^- \pi^+ \pi^-$ relative to the spectrum of $K_1^0 K_1^0 \pi^+ \pi^-$.

- B) η meson ⁷⁾, $J^{PC} = ?$, $I = 0$.

There have been many speculations about the J , P and C quantum numbers of the η . Among the current candidates are 0^{-+} ⁸⁾, 0^{--} ⁹⁾ and 1^{--} ¹⁰⁾. Since the η decays into $(\pi^+ \pi^- \pi^0)$ or into purely neutral modes, only reactions (3) and (5) can be used to identify η

production in $\bar{p}, p$ annihilations. If η 's are found in reaction (3), the hypothesis $J_{\eta}^{PC} = 0^{--}$ can be easily distinguished from 0^{++} or 1^{--} by looking at the Dalitz plot for the reaction $K_1^0 K_1^0 \eta$. In either of the latter two assignments, the dominant configuration is $(0,0)$, a uniform Dalitz plot, while for the 0^{--} case, a very distinctive $(2,2)$ configuration is predicted ¹¹⁾. In fact if the $(\bar{p}, p)$ annihilation region is small ($\ll \frac{\hbar}{m_{\pi} c}$), the centrifugal barrier effects should effectively suppress the $(2,2)$ configuration completely. The comparison of $K^+ K^- \eta$ and $K_1^0 K_1^0 \eta$ would also distinguish 0^{--} from 0^{++} or 1^{--} .

If J_{η}^{PC} is 0^{++} or 1^{--} then the reaction $K_1^0 K_1^0 \eta$ could be a very useful tool to search for $\bar{K}^0 K^0$ and $K \eta$ final state interactions in S states by looking for deviation from the uniform Dalitz plot. The higher orbital angular momentum configurations that could contribute to the production reaction, $(2,2)$ for 0^{++} and $(0,2)$ or $(2,0)$ for 1^{--} , are probably suppressed by the centrifugal barriers.

c) The ξ particle ¹²⁾, $J^{PC} = ?$, $I = 1$.

Several authors ¹³⁾ have proposed that $J_{\xi}^{PC} = 0^{++}$. This assignment implies that $K_1^0 K_1^0 \xi^0$ is forbidden. However, the $\xi^{\pm} \rightarrow \pi^{\pm} + \pi^0$ could be produced in the reactions (6), with the Dalitz plot characterized by a $(1,0)$ configuration predominantly. If $J_{\xi}^{PC} = 1^{--}$, the $K_1^0 K_1^0 (\xi^0 \rightarrow \pi^+ + \pi^-)$ is allowed in the $(0,0)$ configuration. Hence if the ξ is produced in $(\bar{p}, p)$ annihilations, the selection rules offer a good chance of discriminating between various spin and parity assignments for it. [Note that if $J_{\xi}^{PC} = 0^{++}$, the reaction $K_1^0 K_1^0 (\eta \rightarrow \text{neutrals})$ will not be contaminated by $K_1^0 K_1^0 (\xi^0 \rightarrow \text{neutrals})$, so that the discussion of section B can be applied to such events despite the proximity of the η and ξ masses.]

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D) The ω particle ¹⁴⁾, $J = 1^-$, $I = 0$.

In this case one expects $K_1^0 K_1^0 \omega$ in the (0,0) configuration, with the next higher configurations being (0,2) and (2,0). If the centrifugal barrier suppresses these higher configurations sufficiently, deviations from a uniform Dalitz plot can be used to study $(K \bar{K}^0)$ and $(K \omega)$ final state interactions. The $K^+ K^- \omega$ channel should also be predominantly in the (0,0) configuration if no final state interactions are present, and should occur much more often than the $K_1^0 K_1^0 \omega$ reaction in which both K_1^0 's decay via their charged modes.

IV. CONCLUSIONS

If S state $(\bar{p}, p)$ capture really predominates for the reactions $\bar{p} + p \rightarrow K + \bar{K} + X$ many interesting applications can be made with respect to the determination of the quantum numbers of the particle or resonant state X without reference to its mode of decay.

Furthermore, if the $(\bar{p}, p)$ annihilation region is sufficiently small so that all but the lowest orbital angular momentum state configuration are suppressed by centrifugal barriers, these reactions can provide useful hunting grounds for the exploration of $K\bar{K}$ and other final state interactions. We have confined our discussion to "narrow" states X so as to avoid the complications of substantial interferences with non-resonant and overlapping resonant configurations. However, in some of the applications of Section III, interferences with reactions involving other known resonances (e.g., $K^* \rightarrow K + \pi$) cannot be avoided ¹⁴⁾.

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A P P E N D I X

The theoretical mechanism ^{1),2)} invoked to explain the S state annihilation of the ($\bar{p}$, p) system from atomic states of high radial quantum number implies that the triplet and singlet ($\bar{p}$, p) states are independently annihilated. The electromagnetic transitions that play a role are essentially spin independent so that one does not expect any feeding from one spin state to another. Therefore, one expects the simple statistical weights of $\frac{1}{4}$ and $\frac{3}{4}$ for the relative number of singlet and triplet state annihilations, even if the absolute strength of the annihilation reactions were to differ by one or two orders of magnitude for the different spin states.

The reactions proposed by d'Espagnat to test for the frequency of ($\bar{p}$, p) annihilations in S states were

and

Reactions (7) and (8) are forbidden from 1S_0 , while reaction (8) but not (7) is allowed from 3S_1 . For P states, one finds reactions (7) and (8) forbidden for 3P_1 and 1P_1 , and reaction (7) but not (8) allowed for 3P_0 and 3P_2 . If we let χ = ratio of P state to S state capture, a simple counting of the states that can contribute to reactions (7) and (8), when combined with the assumed efficiencies of $\frac{2}{3}$ and 0 for seeing a K_1^0 and a K_2^0 yields

$$\frac{\text{Number of observed events of Eq. (7)}}{\text{Number of observed events of Eq. (8)}} = \frac{\left(\frac{3}{4}\right) \cdot \frac{6}{9} \cdot \frac{1}{2} \cdot \frac{2}{3} \cdot \frac{2}{3}}{\left(\frac{3}{4}\right) \left(\frac{2}{3}\right)} \chi = \frac{2}{9} \chi.$$

8.

Strictly speaking d'Espagnat's test establishes the ratio of p/s state capture for the production of $K^0 + \bar{K}^0$ only, so that an extrapolation is necessary to apply the result of this test to other reactions such as (1).

$$(1) \quad p + \bar{p} \rightarrow K^0 + \bar{K}^0$$

$$(2) \quad p + \bar{p} \rightarrow K^+ + K^-$$

R E F E R E N C E S

- 1) T.B. Day, G.A. Snow and J. Sucher, Phys. Rev. Let. 3, 61 (1959).
- 2) B.P. Desai, Phys. Rev. 119, 1385 (1960).
- 3) Report by D. Morrison at the London Physical Society Meeting, March 1962 ; and private communication.
- 4) B. d'Espagnat, Nuovo Cimento 20, 1217 (1961).
- 5) T.D. Lee and C.N. Yang, Nuovo Cimento (Ser.10) 3, 749 (1956).
- 6) A. Abashian, N. Booth and K. Crowe, Phys. Rev. Let. 5, 258 (1960).
- 7) A. Pevsner et al., Phys. Rev. Let. 7, 421 (1961) ;
P. Bastien et al., Phys. Rev. Let. 8, 114 (1962) ;
E. Pickup et al., Phys. Rev. 125, 2091 (1962) ;
D. Carmony et al., Phys. Rev. Let. 8, 117 (1962).
- 8) L.M. Brown and P. Singer, Phys. Rev. Let. 8, 155 (1962).
- 9) G.L. Shaw and D.Y. Wong, Phys. Rev. Let. 8, 336 (1962).
- 10) J.J. Sakurai, Phys. Rev. Let. 7, 355 (1961) ;
G. Feinberg, Phys. Rev. Let. 8, 151 (1962).
- 11) If $\vec{p}$ = momentum of K^0 in $(K^0, \bar{K}^0)$ rest system, and $\vec{q}$ = momentum of η in $(\bar{p}, p)$ rest system, then the $|\text{amplitude}|^2$ for the reaction $K_1^0 + K_1^0 + \eta$ for 0^{--} is $\sim |(\vec{p} \times \vec{q})(\vec{p} \cdot \vec{q})|^2$.
- 12) R. Barloutaud et al., Phys. Rev. 8, 32 (1962) ;
B. Sechi Zorn, Phys. Rev. Let. 8, 282 (1962).
- 13) R.F. Peierls and S.B. Treiman, Phys. Rev. Let. 8, 339 (1962) ;
G. Feinberg and A. Pais, Phys. Rev. Let. 8, 341 (1962).
- 14) B. d'Espagnat, J. Prentki and Y. Yamaguchi, CERN preprint 2157/TH. 217 ;
C. Bouchiat and G. Flamand, Nuovo Cimento 13, 13 (1962).