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Parity of the antiproton

Jerrold Franklin*

Department of Physics, Technion - Israel Institute of Technology, Haifa, Israel

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It is shown, using an angular momentum argument, that the asymmetry observed in $\bar{p}p \to \pi^+\pi^-$ with polarized targets confirms the expected negative intrinsic parity and negative exchange phase of the $\bar{p}p$ state.

A recent letter by Kalogeropoulis, Chiu, and, Sudarshan (KCS)[1] has pointed out that the observation of asymmetry[2] in $\bar{p}p \to \pi^+\pi^-$ with polarized protons confirms the expected (from general field-theory arguments) negative intrinsic parity of the antiproton with respect to the proton. However, KCS assume the usual exchange property (as in local fermion field theory) for the $\bar{p}p$ system. Since the motivation for questioning the intrinsic $\bar{p}p$ parity ($\eta_{\bar{p}p}$) is the possibility of other choices that might occur in imaginative models, it is also of interest to consider the possibility of unusual exchange properties of the $\bar{p}p$ state.[3] In this note we use an angular momentum argument to show that the asymmetry observed in $\bar{p}p \to \pi^+\pi^-$ requires both the usual intrinsic parity ($\eta_{\bar{p}p} = -1$) and the usual exchange phase ($\tau_{\bar{p}p} = -1$).

The relative intrinsic parity ($\eta_{\bar{p}p}$) of the $\bar{p}p$ system is defined relative to the $\pi^+\pi^-$ system by

$$(-1)^L \eta_{\bar{p}p} = (-1)^J \eta_{\pi^+\pi^-} , \tag{1}$$

while conservation of CP in strong interactions means that the $\bar{p}p$ and $\pi^+\pi^-$ CP eigenvalues are related by

$$-(-1)^S \eta_{\bar{p}p} \zeta_{\bar{p}p} = \eta_{\pi^+\pi^-} \zeta_{\pi^+\pi^-} . \tag{2}$$

The phase ζ results from particle-antiparticle interchange and, in usual field theory, has the value $+1$ for Bose fields and -1 for Fermi fields. We take $\eta_{\pi^+\pi^-} = \zeta_{\pi^+\pi^-} = +1$ (corresponding to the Bose nature of the pion) as confirmed by other examples of $\pi\pi$ final states.[1] KCS assume that $\zeta_{\bar{p}p} = -1$ as in fermion field theory, but we leave open the possibility of another choice.

The total (J) and orbital (L) angular momentum of the $\bar{p}p$ system are related by the angular momentum addition $\vec{J} = \vec{L} + \vec{S}$, where the $\bar{p}p$ spin S can equal 1 or 0. As KCS point out, the asymmetry in $\bar{p}p \to \pi^+\pi^-$ arises from interference between $S_z = \pm 1$ and $S_z = 0$ $\bar{p}p$ states. The $S_z \pm 1$ states are certainly $S = 1$. From Eq. (2), we see that the $\bar{p}p$ system must be in a pure spin state. Thus the $S_z = 0$ $\bar{p}p$ states must also be $S = 1$. We now make the observation that there is no $S_z = L_z = 0$ state for the angular momentum addition $\vec{L} + \vec{1} = \vec{L}$.[4] Therefore we must have $J = L \pm 1$ or $(-1)^J = -(-1)^L$ and, from Eq. (1), we see that $\eta_{\bar{p}p} = -1$, so that the $\bar{p}p$ system has the expected negative intrinsic parity. From Eq. (2) it follows that the exchange phase $\zeta_{\bar{p}p}$ is also negative.

Note added in proof. After this article was submitted for publication, M. I. Shirokov and E. O. Okonov [Phys. Lett. 68B, 88 (1977)] presented an argument equivalent to that in this note.

*On leave from the Department of Physics, Temple University, Philadelphia, Pennsylvania 19122.

[1] T. E. Kalogeropoulos, C. B. Chiu, and E. C. G. Sudarshan, Phys. Rev. Lett. 37, 1037 (1976).

[2] R. D. Erlich *et al.*, Phys. Rev. Lett. 28, 1147 (1972); P. Kalmus, private communication (to Ref. 1).

[3] The effect of unusual exchange properties on the $\bar{p}p \to \pi\pi$ process has been considered by M. I. Shirokov and É. O. Okonov, Zh. Eksp. Teor. Fiz. 39, 285 (1960) [Sov. Phys.—JETP 12, 204 (1961)], but they did not consider polarization experiments at that time.

[4] This follows from a symmetry property of the Clebsch-Gordan coefficients.