SPACE AND CHARGE PARITIES AND MANY-MESON ANNIHILATIONS OF THE PROTON-ANTIPROTON SYSTEM

M. I. SHIROKOV

Joint Institute for Nuclear Research

Submitted to JETP editor January 24, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **41**, 190-196 (July, 1961)

Experiments on the three- and four-meson annihilations of polarized antiprotons in hydrogen are proposed for the purpose of determining the values of the spatial and charge parities of the proton-antiproton system.

1. A paper by Okonov and the writer[1] has stated the problem of checking whether the spatial and charge parities of the system $p\bar{p}$ are just what they should be for a Dirac particle and antiparticle. Experiments on the two-meson annihilation $p + \bar{p} \rightarrow \pi + \pi$ were proposed for this purpose. It is now established that the weight of this channel is very small[2] (evidently there is one two-meson annihilation for each 400 $p\bar{p}$ annihilations*).

In the present paper we show how one can establish the spatial and charge parity types of the $p\bar{p}$ system from experiments on the three- and four-meson annihilation channels, by using polarized antiprotons.[2] In this connection we also discuss a (non-Dirac) choice of the parities which absolutely forbids the two-meson annihilations. This is done because the existence of such annihilations cannot as yet be regarded as firmly established, because of experimental difficulties: it is necessary to exclude cases of annihilation $\bar{p} + p \rightarrow \pi^+ + \pi^-$ plus π^0 or a low-energy γ-ray quantum (such annihilations are not forbidden by this choice of parities). On the other hand, the absence of two-meson annihilations would not be conclusive evidence in favor of this choice of the parities (since other explanations are possible).

The proposed experiments also allow a check of a hypothesis of Okonov,[6] which explains the suppression of the two-meson channel by assuming that $p\bar{p}$ annihilation in the singlet state predominates.

*This fact is not in contradiction with the simplest statistical theories of multiple production, which give the correct mean multiplicity on condition that the interaction volume is taken to be ten Fermi volumes, i.e., about $10 \cdot (4\pi/3)(h/m_\pi c)^3$.[3,4] Obviously the agreement is worse with statistical theories that take the interaction volume to be $(4\pi/3)(h/m_\pi c)^3$. By including the $\pi\pi$ interaction and other considerations, these theories give the correct mean multiplicity, but one gets a two-meson channel of the order of several percent (cf., e. g.[5]).

2. As in [1], the various choices for the parities of the system $p\bar{p}$ are denoted by symbols $\{\pi_{\bar{p}p}, c_{\bar{p}p}\}$, where $\pi_{\bar{p}p}$ is the product of the intrinsic parities of p and $\bar{p}$ and $c_{\bar{p}p}$ is the factor $+1$ or -1 in the expression $\pm 1(-1)^{l+s}$ for the charge parity of the system $p\bar{p}$.

In the Appendix it is shown that for the choice $\{-1, -1\}$ (which forbids two-meson annihilation) the angular distribution $\sigma(\vartheta, \varphi, \vartheta')$ of the reaction $\bar{p} + p \rightarrow \pi^+ + \pi^- + \pi^0$ must go to zero at the points $\vartheta = \vartheta' = 90°$, $\varphi = 0$ or $180°$, whereas with the other choices $\sigma(90°, 0°, 90°)$ does not have to equal zero. ϑ' is the angle between the direction $\mathbf{p}_a$ of the incident beam and the total momentum $\mathbf{p}'$ of the π^+ and π^- mesons (in the c.m.s. of the reaction); ϑ is the angle between $\mathbf{p}'$ and the momentum $\mathbf{p}$ of the π^+ meson, referred to a Lorentz frame in which the total momentum of π^+ and π^- is zero; φ is the angle between the vectors $\mathbf{p}_a \times \mathbf{p}'$ and $\mathbf{p}' \times \mathbf{p}$. By $\sigma(\vartheta, \varphi, \vartheta')$ we mean the angular distribution integrated over the azimuthal angle of the vector $\mathbf{p}'$ (for this it makes no difference whether or not the p or the $\bar{p}$ is polarized).

If $\sigma(90°, 0°, 90°) = 0$, the integral of $\sigma(\vartheta, \varphi, \vartheta')$ over a neighborhood of the point $(90°, 0°, 90°)$ cannot exceed a certain fraction of the total cross section σ of the three-meson channel.

It can be shown that in this version of the theory the angular distribution $\sigma(\vartheta_-, \varphi_-; \vartheta_+, \varphi_+; \vartheta')$ of the reaction $\bar{p} + p \rightarrow \pi^- + \pi^- + \pi^+ + \pi^+$ (integrated over φ') must be zero for φ_-, φ_+ equal to 0 or 180° and $\vartheta_- = \vartheta_+$. Since this is true for arbitrary angles ϑ' and ϑ_- $(= \vartheta_+)$, the integral

$$\int_0^\pi d\cos\vartheta' \int_0^\pi d\cos\vartheta_- \sum_{\alpha,\beta=0,\pi} \sigma(\vartheta_-, \alpha; \vartheta_-, \beta; \vartheta') \quad (1)$$

must also be zero. The definitions of the angles are as follows: ϑ' and φ' are the spherical angles of the sum $\mathbf{p}'$ of the momenta of the two π^- mesons (in the c.m.s. of the reaction) relative to the set of axes $z_a y_a x_a$ (the z_a axis is parallel to the incident beam, and the y_a axis is, for example, along the polarization vector of p); ϑ_- and φ_- are the spherical angles of the momentum $\mathbf{p}_-$ of one of the π^- mesons (in a Lorentz frame in which the total momentum of the two π^- mesons is zero) relative to axes $z'y'x'$ (the z' axis is parallel to $\mathbf{p}'$ and the y' axis is parallel to $\mathbf{z}_a \times \mathbf{p}'$); ϑ_+ and φ_+ are measured in this same set of axes. The expression for $\mathbf{p}_-$ in terms of the momenta $\mathbf{p}_1^-$ and $\mathbf{p}_2^-$ of the two π^- mesons, measured in the c.m.s. of the reaction, is given in Eq. (A.2) of the Appendix.

3. We note that a study of the angular distribution of the annihilation π mesons makes possible a check as to whether the spatial, charge, and combined parities are conserved in the annihilation process. Namely, from invariance under spatial inversion I and the existence of definite parities of p, $\bar{p}$, and the π mesons it follows that $\sigma(\vartheta, \varphi, \vartheta') = \sigma(\vartheta, -\varphi, \vartheta')$ for three-meson annihilation and

$$\sigma(\vartheta_-, \varphi_-; \vartheta_+, \varphi_+; \vartheta') = \sigma(\vartheta_-, -\varphi_-; \vartheta_+, -\varphi_+; \vartheta') \tag{2}$$

for four-meson annihilation (cf. [7]). From invariance under the charge conjugation C it follows that

$$\sigma(\vartheta, \varphi, \vartheta') = \sigma(\pi - \vartheta, \varphi, \pi - \vartheta'),$$
$$\sigma(\vartheta_-, \varphi_-; \vartheta_+, \varphi_+; \vartheta') = \sigma(\vartheta_+, -\varphi_+; \vartheta_-, -\varphi_-; \vartheta'). \tag{3}$$

Finally, from invariance under IC it follows that

$$\sigma(\vartheta, \varphi, \vartheta') = \sigma(\pi - \vartheta, -\varphi, \pi - \vartheta'),$$
$$\sigma(\vartheta_-, \varphi_-; \vartheta_+, \varphi_+; \vartheta') = \sigma(\vartheta_+, \varphi_+; \vartheta_-, \varphi_-; \vartheta'). \tag{4}$$

The angular distributions have these properties for any choice of the parities.

4. The availability of polarized antiprotons[2] allows us to propose the following simple experiment for the determination of the spatial parity of $\bar{p}p$. One needs to compare the signs of the quantities Δ_1 and Δ_2 (see Appendix), which are defined for the reaction $\bar{p} + p \rightarrow \pi^+ + \pi^- + \pi^0$ in the following way:

$$\Delta_1 = \int_0^{\pi/2} d\cos\vartheta' \int_0^{\pi} d\cos\vartheta \Big[\int_{-\pi/2}^{\pi/2} d\varphi' H(\vartheta, \vartheta', \varphi') - \int_{\pi/2}^{3\pi/2} d\varphi' H(\vartheta, \vartheta', \varphi') \Big],$$
$$\Delta_2 = \int_{\pi/2}^{\pi} d\cos\vartheta' \int_0^{\pi} d\cos\vartheta \Big[\int_{-\pi/2}^{\pi/2} d\varphi' H(\vartheta, \vartheta', \varphi') - \int_{\pi/2}^{3\pi/2} d\varphi' H(\vartheta, \vartheta', \varphi') \Big]. \tag{5}$$

Here $H(\vartheta, \vartheta', \varphi') = F(\vartheta, 0°, \vartheta', \varphi') + F(\vartheta, 180°, \vartheta', \varphi')$, where $F(\vartheta, \varphi, \vartheta', \varphi')$ is the angular distribution of the reaction in the case of polarized $\bar{p}$ (or p). Thus one must select cases in which $\mathbf{p}$ lies in the plane formed by the vectors $\mathbf{p}_a$ and $\mathbf{p}'$ (i.e., $\varphi = 0$ or $180°$), divide them into four classes, and compare the signs of the right-left asymmetry for backward emergence (in the c.m.s.) of the π^0 mesons (Δ_1) and for forward emergence (Δ_2). The amount of allowable spread of the angles φ around 0° and 180° depends on the absolute values of Δ_1 and Δ_2 and on the energy of the $\bar{p}$. It can be seen from Table I that the relative sign of Δ_1 and Δ_2 determines the choice of the spatial parity.

In the case of four-meson annihilation everything that has been stated holds for quantities Δ_1 and Δ_2 defined in the following way:

$$\Delta_1 = \int_0^{\pi} d\cos\vartheta_- \int_0^{\vartheta_-} d\cos\vartheta_+ \int_0^{\pi} d\cos\vartheta' \Big[\int_{-\pi/2}^{\pi/2} d\varphi' H - \int_{\pi/2}^{3\pi/2} d\varphi' H \Big],$$
$$\Delta_2 = \int_0^{\pi} d\cos\vartheta_- \int_{\vartheta_-}^{\pi} d\cos\vartheta_+ \int_0^{\pi} d\cos\vartheta' \Big[\int_{-\pi/2}^{\pi/2} d\varphi' H - \int_{\pi/2}^{3\pi/2} d\varphi' H \Big]. \tag{6}$$

Here H means the sum $\sum_{\alpha,\beta=0,\pi} F(\vartheta_-, \alpha; \vartheta_+, \beta; \vartheta', \varphi')$ [cf. Eq. (1)]; it is understood that $\bar{p}$ (or p) is polarized.

We note that the observation of reliable cases of two-meson annihilation, together with equality of the signs of Δ_1 and Δ_2, would mean that the parities are those given by the Dirac theory.

Table I

Parity type	Relative sign of Δ_1 and Δ_2	(R+L) − (F+B)	I (ϑ, ϑ')
{−1, +1} Dirac type	+		
{−1, −1}	+	Vanishes at points $\vartheta = \vartheta' = 90°$, $\varphi = 0°, 180°$	$I(90°, 90°) = 0$
{+1, +1}	—		
{+1, −1}	—		$I(90°, 90°) = 0$

5. More difficult experiments—with both the antiprotons and the target protons polarized—would make it possible to establish the choice of the charge parity. One can see whether the quantity

$$(R+L)-(F+B)=\int_{-\pi/4}^{\pi/4}d\varphi' G + \int_{3\pi/4}^{-3\pi/4}d\varphi' G-\int_{\pi/4}^{3\pi/4}d\varphi' G-\int_{-3\pi/4}^{-\pi/4}d\varphi' G, \qquad (7)$$

(see Table I) is zero at the points $\vartheta = \vartheta' = 90°$, $\varphi = 0$ or $180°$; here $G(\vartheta, \varphi, \vartheta', \varphi')$ is the angular distribution of $\bar{p} + p \rightarrow \pi^+ + \pi^- + \pi^0$ in the case of antiprotons and protons polarized in the same direction perpendicular to the beam.

A distinguishing feature of the choice $c_{\bar{p}p} = -1$ is the vanishing at the point $\vartheta = \vartheta' = 90°$ of the quantity

$$I(\vartheta,\vartheta')=\int_0^{2\pi}d\varphi\Big[\int_0^{2\pi}d\varphi' G(\vartheta,\varphi,\vartheta',\varphi') - \int_0^{2\pi}d\varphi' F(\vartheta,\varphi,\vartheta',\varphi')\Big] \qquad (8)$$

(see Table I). Instead of F one can use the angular distribution from unpolarized $\bar{p}$ and p.

6. For the Dirac choice of the parities it follows from the selection rules for the spatial and charge parities that two-meson annihilation can occur only through the triplet states of the system $\bar{p}p$ (cf. e.g., Table I in reference 1). Okonov[6] has suggested explaining the suppression of two-meson annihilation by the hypothesis that $\bar{p}p$ annihilation is possible only in the singlet state of this system. Then the angular distribution of the annihilation π mesons must not depend on the azimuth φ', even if the antiprotons are polarized. In particular, we must have $\Delta_1 = \Delta_2 = 0$ and $I(\vartheta, \vartheta') = 0$. On this hypothesis there cannot be any dependence of the angular distribution of the annihilation products on the polarization of $\bar{p}$ or p.

In conclusion I express my gratitude to Professor M. A. Markov, V. I. Ogievetskii, and É. O. Okonov for discussions.

APPENDIX

THREE-MESON ANNIHILATION

1. For the reaction $\bar{p} + p \rightarrow \pi^+ + \pi^- + \pi^0$ the selection rules for the spatial and charge parities are

$$-\pi_{\bar{p}p}(-1)^{l_a+l+l'}=+1, \qquad c_{\bar{p}p}(-1)^{l_a+s+l}=+1, \qquad (A.1)$$

l_a is the orbital angular momentum of the system $\bar{p}p$, l is the orbital angular momentum of $\pi^+\pi^-$, l' is the orbital angular momentum of the system $(\pi^+\pi^-)-(\pi^0)$, and s is the total spin of $\bar{p}p$. From Eq. (A.1) we do not get any simple results (such as that annihilation from the s state is forbidden) of the sort we had in the case of two-meson annihilation, where such results make it possible to distinguish the parity types $\{\pi_{\bar{p}p}, c_{\bar{p}p}\}$ in terms of the energy dependence of the cross section. A determination of the parity type in general requires experiments with polarized $\bar{p}$ and p.

2. Let us get from Eq. (A.1) the resulting relations between the amplitudes $\langle \mathbf{p}\mathbf{p}' | R | \mathbf{p}_a m_a m_b \rangle$ for transition from the initial state characterized by the presence of $\bar{p}$ and p with the relative momentum $\mathbf{p}_a$ and spin projections m_a and m_b on the direction of $\mathbf{p}_a$ to a final state with three π mesons in a state described by the momenta $\mathbf{p}$ and $\mathbf{p}'$. $\mathbf{p}$ is the momentum of the π^+ in a Lorentz frame in which the total momentum of π^+ and π^- is zero (the momentum of the π^- in this system is $-\mathbf{p}$). In the c.m.s. of the reaction this total momentum is $\mathbf{p}'$.[7,8] If $\mathbf{p}_1$, $\mathbf{p}_2$, and $\mathbf{p}_3$ denote the momenta of π^+, π^-, and π^0 in the c.m.s. of the reaction, then

$$\mathbf{p}=\mathbf{p}_1+(\mathbf{p}_1+\mathbf{p}_2)\left[\frac{(\mathbf{p}_1+\mathbf{p}_2,\mathbf{p}_1)}{(\mathbf{p}_1+\mathbf{p}_2)^2}\left(\frac{E_{12}}{\varkappa_{12}}-1\right)-\frac{\sqrt{p_1^2+\varkappa^2}}{\varkappa_{12}}\right],$$
$$\mathbf{p}'=\mathbf{p}_1+\mathbf{p}_2=-\mathbf{p}_3, \qquad (A.2)$$

where (cf. [7])

$$E_{12}=\sqrt{p_1^2+\varkappa^2}+\sqrt{p_2^2+\varkappa^2}, \quad \varkappa_{12}=\sqrt{E_{12}^2-(\mathbf{p}_1+\mathbf{p}_2)^2}$$

(κ is the mass of the $\pi^\pm$ meson, and the speed of light has been set equal to unity).

The following expression has been obtained in [7]:

$$\langle \mathbf{p}\mathbf{p}' | R | \mathbf{p}_a m_a m_b\rangle \equiv R_{m_a,m_b}(\vartheta,\varphi,\vartheta',\varphi')$$
$$=\sum_{l,s,m}(4\pi)^{-3/2}(2J+1)\sqrt{2l+1}\,D^l_{0,m}(-\pi,\vartheta,\pi-\varphi)$$
$$\times D^J_{m,m_a+b}(-\pi,\vartheta',\pi-\varphi')\langle lm|R^J|m_a m_b\rangle, \qquad (A.3)$$

$$\langle lm|R^J|m_a m_b\rangle=\sum_{l',l_a,s}\sqrt{\frac{2l'+1}{2J+1}}C^{Jm}_{lml'0}\langle ll'|R^J|sl_a\rangle$$
$$\times\sqrt{\frac{2l_a+1}{2J+1}}C^{sm_a+m_b}_{1/2m_a\,1/2m_b}C^{Jm_a+m_b}_{sm_a+m_b\,l_a0}, \qquad (A.4)$$

ϑ' and φ' are the spherical angles of $\mathbf{p}'$ relative to axes with the z_a axis parallel to $\mathbf{p}_a$; ϑ and φ are the spherical angles of $\mathbf{p}$ relative to axes $z'y'x'$ (the z' axis is parallel to $\mathbf{p}'$, and the y' axis is parallel to $[\mathbf{p}_a \times \mathbf{p}']$). Furthermore, $D^l_{m,n}(\Phi_2, \theta, \Phi_1) = e^{-im\Phi_2}\mathscr{P}^l_{mn}(\cos\theta)e^{-in\Phi_1}$, where the function $\mathscr{P}^l_{mn}$ differs from the function

P^l_{mn} defined in [9] by the factor i^{n-m} and is equal to the function $d^l_{m,n}$ defined in[10].

In the right member of Eq. (A.4) let us insert under the summation sign a factor $c_{\bar{p}p}(-1)^{l_a+s+l}$, which is equal to +1 by Eq. (A.1); we then use a property of the Clebsch-Gordan coefficients:

$$C^{Jm_a+m_b}_{sm_a+m_b l_a 0} = (-1)^{J-s-l_a} C^{J,-m_a-m_b}_{s,-m_a-m_b,l_a 0},$$

$$C^{sm_a+m_b}_{1/2 m_a 1/2 m_b} = C^{s,-m_a-m_b}_{1/2 -m_b 1/2 -m_a}. \qquad (A.5)$$

We then can verify that the right member of Eq. (A.4) is the element $\langle lm | R^J | -m_b - m_a \rangle$ multiplied by $c_{\bar{p}p}(-1)^{l+J}$; that is,

$$\langle lm | R^J | m_a m_b \rangle = c_{\bar{p}p}(-1)^{l+J} \langle lm | R^J | -m_b - m_a \rangle. \qquad (A.6)$$

Substituting the right member of Eq. (A.6) for $\langle lm | R^J | m_a m_b \rangle$ in the right member of Eq. (A.3), and using the equation (for integer j)

$$D^j_{m,n}(-\pi, \theta, \pi - \Phi)$$
$$= (-1)^{j-m} D^j_{m,-n}(-\pi, \pi - \theta, \pi + \Phi)$$
$$= (-1)^{j-n} D^j_{-m,n}(-\pi, \pi - \theta, \pi - \Phi), \qquad (A.7)$$

we get the following consequence of invariance under the charge conjugation C:

$$R_{m_a, m_b}(\vartheta, \varphi, \vartheta', \varphi') = c_{\bar{p}p} R_{-m_b, -m_a}(\pi - \vartheta, \varphi; \pi - \vartheta', -\varphi'). \qquad (A.8)$$

Analogously, we can get (cf. [7] and [11]) the consequence of invariance under spatial inversion:

$$R_{m_a, m_b}(\vartheta, \varphi, \vartheta', \varphi')$$
$$= \pi_{\bar{p}p}(-1)^{m_a+m_b} R_{-m_a, -m_b}(\vartheta, -\varphi, \vartheta', -\varphi'). \qquad (A.9)$$

The dependence of $R_{m_a,m_b}(\vartheta, \varphi, \vartheta', \varphi')$ on φ' is known [see Eq. (A.3)]. Therefore we can remove a factor $\exp\{i(m_a + m_b)\varphi'\}$ from the equations (A.8) and (A.9). Hereafter we shall not write the argument φ'.

The relations (A.8) and (A.9) and some combinations of these relations are written out in Table II for the various parity types. The following notations have been used:

$$R_{-1/2,-1/2}(\vartheta, \varphi, \vartheta') = a, \quad R_{-1/2,+1/2} = b,$$
$$R_{+1/2,-1/2} = c, \quad R_{+1/2,+1/2} = d.$$

Then $R_{-1/2,-1/2}(\vartheta, -\varphi, \vartheta') = a'$, and similarly for b, c, and d;

$$R_{-1/2,-1/2}(\pi - \vartheta, \varphi, \pi - \vartheta')$$
$$= \tilde{a}; \quad R_{-1/2,-1/2}(\pi - \vartheta, -\varphi, \pi - \vartheta') = \tilde{a}'$$

and similarly for b, c, and d.

3. If the beam and the target are polarized in the direction y_a (perpendicular to $\mathbf{p}_a$), the angular distribution of π^+, π^-, π^0 is of the form (cf., e.g., [11])

$$G(\vartheta, \varphi, \vartheta', \varphi') \sim W(\vartheta, \varphi, \vartheta') + \sqrt{2}\,\tilde{P}_y[-\mathrm{Im}\,\tilde{W}_- \cos\varphi'$$
$$+ \mathrm{Re}\,\tilde{W}_- \sin\varphi'] + \sqrt{2}\,P_y[-\mathrm{Im}\,W_- \cos\varphi'$$
$$+ \mathrm{Re}\,W_- \sin\varphi'] - \tilde{P}_y P_y[\mathrm{Re}\,W_{-,-} \cos 2\varphi'$$
$$+ \mathrm{Im}\,W_{-,-} \sin 2\varphi' + \mathrm{Re}\,W_{-,+}]. \qquad (A.10)$$

The values of the antiproton polarization $\tilde{P}_y$ and the target proton polarization P_y are defined in the usual way as the average values of the y component of the spin operator, $\sigma_y/2$. The coefficients W that appear in Eq. (A.10) can be expressed in terms of the transition amplitudes a, b, c, d:

$$W(\vartheta, \varphi, \vartheta') = \tfrac{1}{4}[|a|^2 + |b|^2 + |c|^2 + |d|^2],$$
$$\tilde{W}_- = (ac^* + bd^*)/2\sqrt{2}, \qquad W_- = (ab^* + cd^*)/2\sqrt{2},$$
$$W_{-,-} = ad^*/2, \qquad W_{-,+} = -bc^*/2. \qquad (A.11)$$

It can be seen from Table II that $b = +\tilde{b}$ or $b = -\tilde{b}$, depending on the parity type, i.e., b does not (or does) change sign when ϑ and ϑ' are replaced by $\pi - \vartheta$ and $\pi - \vartheta'$, respectively. We shall say that the function b is even (or odd) relative to the point $\vartheta = \vartheta' = 90°$ (for any φ). From Table II and Eq. (A.11) it follows that for $\pi_{\bar{p}p} = -1$ the coefficients $\tilde{W}_-$ and W_- for $\varphi = 0$ and 180° are even functions relative to the point $\vartheta = \vartheta' = 90°$, and for $\pi_{\bar{p}p} = +1$ they are odd functions. The functions $W_{-,-}$ and $W_{-,+}$ are even functions in all parity types; in some types they vanish at the points $\vartheta = \vartheta' = 90°$, $\varphi = 0$ and 180°, or on the line $\vartheta = \vartheta' = 90°$, φ arbitrary. It can also be seen that for the type $\{-1, -1\}$ all of the functions a, b, c, d, and consequently all of the W coefficients are zero at the points $\vartheta = \vartheta' = 90°$, $\varphi = 0$ or 180°. Along with these quantities the integral

Table II

Parity type	I	C	IC
$\{-1, +1\}$ Dirac type	$a=d'$, $b=-c'$	$a=\tilde{d}$, $b=\tilde{b}$, $c=\tilde{c}$	$a=\tilde{a}'$, $d=\tilde{d}'$
$\{-1, -1\}$	$a=d'$, $b=-c'$	$a=-\tilde{d}$, $b=-\tilde{b}$, $c=-\tilde{c}$	$a=-\tilde{a}'$, $d=-\tilde{d}'$
$\{+1, +1\}$	$a=-d'$, $b=c'$	$a=\tilde{d}$, $b=\tilde{b}$, $c=\tilde{c}$	$a=-\tilde{a}'$, $d=-\tilde{d}'$
$\{+1, -1\}$	$a=-d'$, $b=c'$	$a=-\tilde{d}$, $b=-\tilde{b}$, $c=-\tilde{c}$	$a=\tilde{a}'$, $d=\tilde{d}'$

$$\int_0^{2\pi} d\varphi' G(\vartheta, \varphi, \vartheta', \varphi') \equiv \sigma(\vartheta, \varphi, \vartheta')$$

also vanishes at this point (see Article 2 of the main text).

In processing the experimental data one must obtain from Eq. (A.10) the coefficients of cos φ' and cos $2\varphi'$ and that of $\widetilde{P}_y P_y$ Re $W_{-,+}$. In some cases it is not necessary to study the behavior of these coefficients as functions of ϑ, φ, ϑ'; it is enough to consider certain integrals of the coefficients over these angles. The recipes given here for distinguishing between the parity types correspond precisely to the determination of the coefficients and the subsequent integration (if this is possible).

We note that for the determination of $\pi_{\bar{p}p}$ it would be sufficient in principle to use only the invariance under the inversion I. For such a procedure, however, it is necessary to know the signs of the polarizations of $\bar{p}$ and p (i.e., to know whether $\widetilde{P}_y$ and P_y are positive or negative) (cf. [12]).

Note added in proof (June 15, 1961). At the present time (June, 1961) it has been definitely established that there are two-meson $\bar{p}p$ annihilations [see G. R. Lynch et al., Bull. Am. Phys. Soc. II, **6**, 40 (1961)]. Therefore agreement of the signs of Δ_1 and Δ_2 would mean that the parities are those of the Dirac theory.

A. Pais has called the writer's attention to the fact that he had previously [Phys. Rev. Letters **3**, 242 (1959)] pointed out certain symmetries of the angular distribution of the products of $\bar{p}p$ annihilation which follow from conservation of the charge and combined parities. It can be shown that the first equations in the relations (3) and (4) of the present paper are equivalent to Pais's relations (5) and (6).

[1] M. I. Shirokov and É. O. Okonov, JETP **39**, 285 (1960), Soviet Phys. JETP **12**, 204 (1961).

[2] O. Chamberlain, Proc. 1960 Int. Conf. on High Energy Physics at Rochester, Univ. of Rochester, 1960, p. 653.

[3] E. Segrè, Ann. Rev. Nucl. Sci. **8**, 127 (1958).

[4] B. R. Desai, Phys. Rev. **119**, 1390 (1960).

[5] E. Eberle, Nuovo cimento **8**, 610 (1958).

[6] É. O. Okonov, JETP **39**, 1059 (1960), Soviet Phys. JETP **12**, 738 (1961).

[7] M. I. Shirokov, JETP (in press).

[8] R. H. Dalitz, Phys. Rev. **94**, 1046 (1954).

[9] Gel'fand, Minlos, and Shapiro, Predstavleniya gruppy vrashchenii i gruppy Lorentsa (Representations of the Rotation Group and the Lorentz Group), Fizmatgiz, 1958, Part I, Sec. 7.

[10] M. Jacob and G. C. Wick, Ann. Phys. **7**, 404 (1959).

[11] M. I. Shirokov, JETP **36**, 1524 (1959), Soviet Phys. JETP **12**, 1081 (1961).

[12] S. M. Bilenky, Nuovo cimento **10**, 1049 (1958). R. H. Capps, Phys. Rev. **115**, 736 (1959).

Translated by W. H. Furry
38