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Parity non-conservation in pion production

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Recent experiments ¹⁾ to detect an asymmetry proportional to $\langle \vec{\sigma} \rangle \cdot \vec{k}_\pi$ and thus a parity non-conserving effect in meson production in oriented nucleon collisions have shown little evidence for such an effect. Fubini and Walecka ²⁾ have investigated the effect of a possible parity violation in the strong K-hyperon-nucleon interaction on low energy pion-nucleon scattering. They have shown that the possible parity-mixing parameters in pion-nucleon scattering are largest in the $J=\frac{1}{2}$ channel in which they are linear in the meson momentum but that they do not exceed a few percent even with maximum parity violation in the K-hyperon-interaction. The upper limits are $|\epsilon_{31}| < \frac{q}{\mu} \times 1\%$, $|\epsilon_{11}| < 2\frac{q}{\mu} \times 1\%$, where $\epsilon_{2T,2J}$ is the mixing parameter in the J,T channel. Fubini and Walecka conclude that parity violation effects are expected to be small in low energy pion physics. In this note we make an approximation to the asymmetry possible in meson production in nucleon-nucleon collisions using a crude form of the Weizsäcker-Williams method to relate the production asymmetry to the mixing parameters in pion-nucleon scattering.

The analysis of Fubini and Walecka gives a transition matrix

$$M = f_1 + f_2 \cos\theta + i f_2 \vec{\sigma} \cdot \hat{n} + g \vec{\sigma} \cdot (\hat{q}_1 + \hat{q}_2) \quad (1)$$

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where $\hat{n}$ is the normal to the scattering plane and $\underline{q}_1$ and $\underline{q}_2$ are the initial and final meson momenta. f_1 and f_2 are the parity conserving amplitudes while g is the parity non-conserving amplitude given by

$$g_{J=\frac{1}{2}} = \epsilon_{J=\frac{1}{2}} \frac{(e^{2i\delta_1} - e^{2i\delta_0})}{2iq} \quad (2)$$

in the $J=\frac{1}{2}$ channel. δ_0 and δ_1 are the s- and p-wave phase shifts. It is assumed that the parity mixing effect is small so that only the off-diagonal elements in the S-matrix are changed, and these linearly in ϵ .

To use the Weizsäcker-Williams approach we first compute the cross-section for meson scattering on a polarized nucleon. It is given by

$$\begin{aligned} \frac{d\sigma}{d\Omega} = & |f_1|^2 + |f_2|^2 + (f_2^* f_1 + f_1^* f_2) \cos\theta \\ & + 2 \operatorname{Re} \left[(f_1^* + f_2^* \cos\theta) g \sin\theta \sin\phi - i f_2^* f_1 \sin\theta \cos\phi \right] \\ & + 2 |g|^2 (1 + \cos\theta) \end{aligned} \quad (3)$$

where the nucleon is oriented in the y-direction and the pion wave is incident along the z-direction. Bearing in mind the experiment of Davis et al.¹⁾, we consider the case of π^0 production at 90° in the laboratory due to polarized neutrons of about 490 MeV incident on protons. (The cross-section for π^0 production is much larger for np than for nn at this energy). For laboratory π^0 's of 140 MeV, $\theta \approx 142^\circ$ in the moving frame. The asymmetry can be related to the cross-sections for elastic scattering of π^0 's and charge-exchange scattering of π^+ 's on polarized neutrons at this angle. If we make the plausible assumption that the dominant production channel is through the $J=\frac{3}{2}$, $T=\frac{3}{2}$ state³⁾, we retain in (1) the parity conserving amplitude corresponding to this channel only and obtain

$$\begin{aligned}
\lambda &= \frac{\sigma_{\text{prod.}}^{\parallel} - \sigma_{\text{prod}}^{\perp}}{\sigma_{\text{prod}}^{\parallel} + \sigma_{\text{prod}}^{\perp}} \\
&= \frac{\int N(q) \operatorname{Re} \int (f_1^* + f_2^* \cos \theta) \sin \theta (2g^{3/2} - g^{1/2}) dq}{\int N(q) \int |f_1|^2 + |f_2|^2 + (f_2^* f_1 + f_1^* f_2) \cos \theta dq}
\end{aligned}
\tag{4}$$

$N(q)$ is the number of Weizsacker-Williams neutral pions of momentum q in the meson cloud ⁴⁾ and g^T the parity non-conserving amplitude in the isotopic T-state. Expanding the amplitudes in partial waves, e.g.

$$g = \sum_{\ell=1}^{\infty} (g_{\ell+} - g_{\ell-}) P_{\ell}'(\cos \theta)$$

we keep the $\ell=1$, $J=3/2$ terms for f and the $\ell=0,1$, $J=\frac{1}{2}$ terms for g . Taking the Fermi-type phase shifts, so that all angles are small except δ_{33} we obtain

$$\lambda = \frac{\int A(\theta) N(q) \int \epsilon_{11}(\delta_1 - \delta_{11}) - 2\epsilon_{31}(\delta_3 - \delta_{31}) \sin 2\delta_{33} dq}{\int B(\theta) N(q) \sin^2 \delta_{33} dq}
\tag{5}$$

One sees that for Fermi type phase shifts $(\delta_1 - \delta_{11}) > 0$, $(\delta_3 - \delta_{31}) < 0$ and the asymmetry will be largest when ϵ_{11} and ϵ_{31} have the same sign. Taking the maximum allowed ϵ 's of reference ²⁾ we can estimate the integrals over q rather crudely, hoping that, since λ is a ratio of cross sections, the detailed form of $N(q)$ will be unimportant. The asymmetry not only depends on the

relative sign of the ϵ 's but is also rather sensitive to the small phases and therefore cannot be estimated very precisely. It is, however, possible to give an upper bound to λ ; this is all that is feasible in any case, since only the bounds of the E 's are known. This upper bound to λ varies between 0.3 % and 1 % depending on the phase shift taken. The small bound to λ is obtained from the Chiu and Lomon ⁵⁾ phases $\delta_1 - \delta_{11} \div 11^\circ$ and $\delta_3 - \delta_{31} \div 8^\circ$; the larger from the Bethe de-Hoffman ⁶⁾ phase shifts.

Such upper bounds imply that the pion production experimental results of the U.C.L - Harwell group at CERN are not inconsistent with maximum parity violation in K - hyperon interactions ^{*)}. At the lower bias of the experiments, mesons of considerably lower energy are included and these would give a lower upper bound to λ due to the smaller phases and mixing parameters in (5). On the other hand, the computation is less reliable at such lower energies. Of course in low energy nucleon processes, the experimental upper limit on the parity non-conserving amplitude is much smaller ($\sim 4 \times 10^{-5}$).

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*) It should also be noted that the latest Berkeley results show no evidence for parity non-conservation in production.

R E F E R E N C E S

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