Vol. 31 (2000) ACTA PHYSICA POLONICA B No 10–11

ISOSPIN VIOLATION IN PION PRODUCTION*

J.A. Niskanen

Department of Physics, University of Helsinki
P.O. Box 9, FIN–00014, Finland

(Received June 6, 2000)

The charge symmetry breaking forward-backward asymmetry of the cross section in $np \to d\pi^0$ is discussed near threshold. Among standard sources of isospin breaking the mixing of the π and η mesons shows up as strongly dominant at these energies. This contrasts elastic np scattering or $np \to d\pi^0$ in the Δ region, where other mechanisms dominate. However, QCD based effective field theory suggests an even more important symmetry breaking mechanism.

PACS numbers: 11.30.Hv, 24.80.Dc, 25.40.Qa

1. Introduction

Charge symmetry is the best known and most accurate flavour symmetry, a property of quarks. However, it is broken also in strong interaction, not only electromagnetic, and this breaking (CSB) may have potential use in testing our current understanding of QCD. It has been studied for decades in the mirror systems *nn vs pp* using low-energy NN scattering and mirror nuclei [1,2]. However, here the responsible interaction, proportional to the total isospin operator $\tau_{10} + \tau_{20}$, acts only in isospin one states and cannot change the value of the isospin. In contrast, a CSB force proportional to either $\tau_{10} - \tau_{20}$ or $(\vec{\tau}_1 \times \vec{\tau}_2)_0$ necessarily changes the isospin and so must act only in the np system, where both isospin zero and one are allowed. These so called class IV forces have three main sources, which are roughly equally important in elastic scattering: *(i)* the np-mass difference, *(ii)* $\rho^0\omega$-meson mixing and *(iii)* the magnetic interaction of the neutron with the proton current. A decade ago their effect was first seen experimentally as a difference of the neutron and proton analyzing powers $\Delta A = A_n - A_p$ in polarized np scattering and now there are data at three different energies [3].

* Presented at the Meson 2000, Sixth International Workshop on Production, Properties and Interaction of Mesons, Cracow, Poland, May 19–23, 2000.

Class IV forces can also show up in pionic inelasticities. Namely, isospin conserving mechanisms in $NN \rightarrow d\pi$ would allow only isospin one initial states. This sets strict constraints to the spins and parities of the initial states *vs* the angular momentum of the final state pion: for odd l_π only singlet-even initial states are possible and for even l_π only triplet-odd. This separation of initial spins for different parities leads to a symmetric unpolarized cross section [4]. Obviously a class IV force can generate some allowed isospin one component in otherwise forbidden isospin zero initial states with opposite spin-parity assignments. Then the cross section will no more be exactly symmetric about 90°. This minute asymmetry in $np \rightarrow d\pi^0$ is being measured at TRIUMF [5].

As an interference of opposite parity amplitudes, s- and p-wave pions, the asymmetry should vanish at threshold faster than the cross section. However, there are experimental advantages at threshold allowing smaller relative asymmetries to be detected than at higher energies [5]. Theoretically it is intriguing that at threshold there is less cancellation of possible $\eta\pi$ mixing effects than at higher energies studied in Ref. [6] suggesting this mixing as dominant. This talk discusses predictions for the asymmetry in the threshold region where the experiment is performed. A more detailed account can be found in [7].

Normally the CSB effects are very small, the scale being of the relative np mass difference. However, in QCD the mass difference of the u and d quarks is not small compared to their current masses. QCD based effective field theory suggests an isospin symmetry violating part due to this difference in pion-nucleon scattering [8]. The influence of this term in pion production and its possibly important implications are also shortly discussed.

2. Theory

A standard source of the class IV force, dominant in np elastic scattering experiments above pion threshold so far, is the np mass difference in pion exchange. Taking this into account in the pion-nucleon vertex the nonrelativistic coupling becomes

$$H_{\pi NN} = -\frac{f}{\mu}\left[\vec{\sigma}\cdot\nabla\,\vec{\phi}\cdot\vec{\tau} + \delta\,\vec{\sigma}\cdot\nabla\phi_0 + \delta\,\vec{\sigma}\cdot(\vec{p}+\vec{p}\,')(\vec{\tau}\times\vec{\phi})_0\right] \qquad (1)$$

with $\delta = (M_n - M_p)/(M_n + M_p)$. Here the first term is the normal isoscalar interaction giving rise to the standard OPE potential. The initial and final momenta $\vec{p}$ and $\vec{p}\,'$ operate on nucleons and ∇ on the pion field assumed a plane wave. The latter two isovector terms give rise to a CSB potential of the form (using the usual notations of the literature [6])

$$V_\delta = \delta\frac{f^2}{4\pi}\frac{\mu}{3}, \Big\{(\vec\tau_1+\vec\tau_2)_0[S_{12}V_T(\mu r)+\vec\sigma_1\cdot\vec\sigma_2 V_C(\mu r)] -6(\vec\tau_1\times\vec\tau_2)_0(\vec\sigma_1\times\vec\sigma_2)\cdot\vec L V_{\rm LS}(\mu r)\Big\}. \quad (2)$$

The first part conserves the isospin, while the latter term changes both the spin and isospin, *i.e.* it couples the two possible spins for a given $L=J$ partial wave. This source of isospin breaking in the present reaction is shown in Figs. 1a, b.

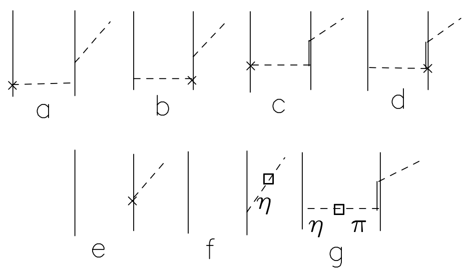

Fig. 1. Isospin breaking mechanisms in $np\to d\pi^0$: isospin mixings in the initial state due to mass difference δ dependent potentials (a–d), CSB production vertices (e and f) and transition potential due to $\eta\pi$ mixing (g). CSB vertices are denoted by a cross or box.

In pion physics the coupling of the pion and nucleon to the $\Delta(1232)$ resonance is always essential. As above for nucleons, one gets an isovector transition potential from the mass differences (also between different charge states of the Δ, Figs. 1c,d)

$$V_\delta^{\rm tr}({\rm OPE}) = \frac{\delta f f^*}{4\pi}\frac{\mu}{3}\Big\{T_{10}\,[S_{12}^{\rm II}\,V_T(\mu r)+\vec S_1\cdot\vec\sigma_2\,V_C(\mu r)] - 6(\vec T_1\times\vec\tau_2)_0\,(\vec S_1\times\vec\sigma_2)\cdot\vec L\,V_{\rm LS}(\mu r)\Big\}+(1\leftrightarrow 2). \quad (3)$$

Here the transition spin (isospin) $\vec S$ ($\vec T$) changes spin (isospin) $\frac{1}{2}$ particles to those with $\frac{3}{2}$ [9]. The mass difference between consecutive charge states of the Δ has been assumed to be the same as for the nucleons. In the tensor operator $S_{12}^{\rm II}$ one spin operator has been replaced by the relevant transition spin operator. Contrary to the case of the NN interaction, now also the first term in (3) can cause a transition from an isospin zero NN state to an intermediate ΔN state which can participate in pion production.

In addition to isospin mixing in the initial np state, the pion coupling (1) gives a possibility for isospin breaking also in the final pion producing vertex

(Fig. 1e). Namely the middle term is in form equivalent to an isoscalar meson production operator and so there is a finite amplitude of *direct transition* from an initial isospin zero state to the deuteron state plus a pion.

Analogously with the above effective isoscalar meson coupling, also production of first a true off-shell isoscalar pseudoscalar meson (η or η') is possible with its subsequent transformation into a pion, because there is a nonvanishing mixing between the η and π mesons [10] (Fig. 1f). The coupling of pions to nucleons via this mechanism is of the form

$$H_{\eta\pi}^{\rm prod} = -\frac{f_\eta}{\mu}\frac{\langle\eta|H|\pi\rangle}{\mu^2-\eta^2}\,\vec{\sigma}\cdot\nabla\phi_0. \tag{4}$$

Using the mixing matrix $\langle\eta|H|\pi\rangle = -5900\,\mathrm{MeV}^2$ [10] and the ηNN coupling $G_\eta^2/4\pi = 3.68$ [11] with $f_\eta = G_\eta\mu/2M$ it can easily be seen that the strength of this contribution should be about 15 times larger than the isoscalar coupling of the pion from the np mass difference in Eq. (1). So one would expect this to be a very important effect which is further enhanced by the η' meson mixing with the mixing matrix element -5500 MeV^2 [10]. (The coupling of the η' to the nucleon is taken to be the same.)

In the NN sector $\eta\pi$ mixing cannot mix isospins, but it can produce an $NN \to \Delta N$ transition potential, which can act also in isospin zero initial states (Fig. 1g). Due to the rather strong effective coupling seen above, also this should have a significant effect in pion production. In the Δ region, however, the two different $\eta\pi$-mixing contributions tend to cancel to a large extent [6].

There are great uncertainties in the ηNN and $\eta' NN$ coupling strengths. Much smaller values are also quoted from pion photoproduction [12] and a sensitive probe for this coupling is desirable to clarify the situation. The value used above is obtained in a meson exchange NN potential model fit to elastic NN scattering and is consistent with the range 2–7 given in various versions of the Bonn potentials [13]. Another uncertainty is related to a controversy of off-shell $\rho\omega$-meson mixing and is not considered here.

In calculations of the above mechanisms also pion s-wave rescattering from the second nucleon is taken into account in production, but no isospin violation has been associated with πN scattering. However, QCD via effective field theory indicates that there is a low-energy isospin asymmetry violation arising from the up and down quark mass difference, which can be described as [8]

$$H_{\rm qm}^{(1)} = -\frac{\delta m_N}{2}\left(\tau_0 - \frac{2}{DF_\pi^2}\phi_0\vec{\phi}\cdot\vec{\tau}\right), \tag{5}$$

where $F_\pi = 186$ MeV is the pion decay constant, $D = 1+\phi^2/F_\pi^2$ and δm_N is the quark mass difference contribution to the nucleon mass splitting typically estimated to be of the order of 3-4 MeV. Here the second term would contribute to pion production as isospin symmetry violating rescattering off the second nucleon. One may note that the strength of this term in the πN interaction is comparable to the strength of the standard chirally suppressed isoscalar scattering at threshold. By its very size this new term is then of great interest for the potential success of experiments. Even more importantly, this term is rather an automatic consequence of QCD in effective field theories and has even less uncertainty in its parameters than the above discussed ηN coupling constant. So the measurement of CSB in pion production can be an essential test of these theories, if for some reason this new effect is not dwarfed by the $\eta\pi$ mixing.

3. Results and conclusion

The quantity of experimental interest here is the integrated forward-backward asymmetry divided by the total reaction cross section

$$A_{\mathrm{fb}} \equiv \int_0^{\pi/2} [\sigma(\theta) - \sigma(\pi - \theta)] \sin\theta d\theta \Bigg/ \int_0^{\pi} \sigma(\theta) \sin\theta d\theta. \tag{6}$$

Here the angle is the CM angle between the detected deuteron and incident neutron directions. The results are shown in Fig. 2 at the energy 279.5 MeV of the TRIUMF experiment [5]. The two dotted curves show the effects due to the np (and the Δ) mass differences, while the larger $\eta\pi$ mixing contributions are given by the dashed curves. The contributions from the production vertices and meson exchange potentials are separated. The total

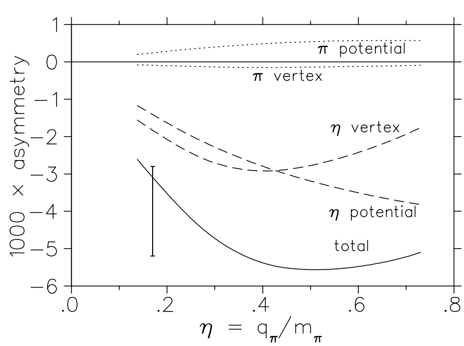

Fig. 2. Contributions dependent on the relative mass difference δ (dotted) and meson mixing $\langle\eta|H|\pi\rangle$ (dashed) to the total integrated forward–backward asymmetry (solid). The "data" point expresses the energy and expected error of the experiment [5].

sum is the solid curve. In comparison to meson mixing the mass difference effect is hopelessly small, but if the ηNN coupling is as large as used here its effect could be seen in the experiment.

However, the isospin conserving reaction is dominated by s-wave πN rescattering at threshold and so the explicit CSB contribution suggested in [8] must also be considered. A preliminary calculation [14] indicates its effect to be 3–4 times the size of the total $\eta\pi$ mixing effect making it by far the dominant mechanism. It is unlikely that any reasonable ηN coupling constant alone could make the conventional hadron level mechanism competitive.

Also one might note that the ρ and $\rho\omega$-mixing effects as well as the electromagnetic interaction are probably significantly smaller than $\eta\pi$ mixing or the above QCD effect at threshold. They tend to be in the same order of magnitude as the pion effects. As a summary, it is likely that CSB threshold production is strongly dominated either by $\eta\pi$ mixing or the quark mass difference effect in πN rescattering. In either case CSB measurements have a great potential of yielding important information on very basic physics.

I thank U. van Kolck and G.A. Miller for communications. This work was partly supported by the Academy of Finland and the Finnish Academy of Science and Letters via the Vilho, Yrjö and Kalle Väisälä Foundation.

REFERENCES

[1] G.A. Miller, B.M.K. Nefkens, I. Slaus, *Phys. Rep.* **C194**, 1 (1990).

[2] G.A. Miller, W.T.H. Van Oers, in *Fundamental Symmetries,* edited by W.C. Haxton and E.M. Henley, World Scientific, Singapore 1995, p. 127.

[3] R. Abegg *et al.*, *Phys. Rev.* **D39**, 2464 (1989); S.E. Vigdor *et al.*, *Phys. Rev.* **C46**, 410 (1992); J. Zhao *et al.*, *Phys. Rev.* **C57**, 2126 (1998).

[4] S. Barshay, G.M. Temmer, *Phys. Lett.* **12**, 728 (1964).

[5] TRIUMF experiment E704, spokespersons A.K. Opper and E. Korkmaz.

[6] J.A. Niskanen, M. Sebestyen, A.W. Thomas, *Phys. Rev.* **C38**, 838 (1988).

[7] J.A. Niskanen, *Few-Body Systems* **26**, 241 (1999).

[8] U. van Kolck, Ph.D. dissertation, U. of Texas, 1993; *Few-Body Systems* Suppl. **9**, 444 (1995).

[9] G.E. Brown, W. Weise, *Phys. Rep.* **C22**, 279 (1975).

[10] S.A. Coon, *et al.*, *Phys. Rev.* **D34**, 2784 (1986).

[11] O. Dumbrajs *et al.*, *Nucl. Phys.* **B216**, 277 (1983).

[12] L. Tiator *et al.*, *Nucl. Phys.* **A580**, 455 (1994).

[13] C. Elster, R. Machleidt, K. Holinde, *Phys. Rep.* **C149**, 1 (1987); R. Machleidt, *Adv. Nucl. Phys.* **19**, 189 (1989).

[14] U. van Kolck, G.A. Miller, J.A. Niskanen, work in progress.