Hadronic parity violation in few-nucleon systems

A. Baroni[1] L. Girlanda [2] [3] R. Schiavilla [1] [4] and M. Viviani [5]

[1]Department of Physics, Old Dominion University, Virginia, USA

[2]Dipartimento di Matematica e Fisica, Università del Salento, Italy

[3]Istituto Nazionale di Fisica Nucleare sez. di Lecce, Italy

[4]Jefferson Lab, Virginia, USA

[5]Istituto Nazionale di Fisica Nucleare sez. di Pisa, Italy

The field of hadronic parity violation has acquired in recent years renewed interest, due to a new generation of experiments involving few-nucleon systems, which are being completed or planned at cold neutron facilities, such as the Los Alamos Neutron Science Center, the NIST Center for Neutron Research and the Spallation Neutron Source at Oak Ridge. The parity violating (PV) effects in these systems are expected to be very tiny and the required accuracy for such experiments is of the order of 10^{-7}. Traditionally, the standard framework to analyze nuclear parity violation has been the so called DDH model [1], based on the meson exchange mechanism. More recently the problem has been recast in the framework of chiral effective theory. In this theory the pion couples to nucleons by powers of its momentum p, and the relevant Lagrangian, the most general one respecting the symmetries of the underlying theory, can be expanded in powers of $p/\Lambda_{\rm H}$, where $\Lambda_{\rm H}$ is the hadronic scale, of the order of the mass of the first hadrons not protected by chiral symmetry, $\Lambda_{\rm H} \sim 1$ GeV. This (perturbative) framework has the advantage of being systematic, in the sense that the theoretical uncertainty can be estimated and can in principle be reduced by including higher order of the low-energy expansion. A further advantage is the clear connection with QCD, the underlying theory of strong interactions, and its symmetries. The parity-violating pion-nucleon Lagrangian has been worked out in Ref. [2] up to $O(p)$. This Lagrangian includes a Yukawa-type pion-nucleon interaction without derivatives, with the corresponding low-energy constant (LEC) known as the weak pion-nucleon coupling constant, h^1_π, giving rise to the longest-range contribution to the PV nuclear potential. In addition, up to the next-to-next-to leading order (N2LO) [3], there is a medium-range contribution, from two-pion exchange (TPE) processes, and a short range component from two-nucleon contact terms. Subsequent expressions for the TPE diagrams [?] differ from the ones reported in [3]. We have therefore rederived again the PV nuclear potential at N2LO, using also the fact that, as established in Ref. [4], there exist only five independent leading-order contact terms. To this aim we used time-ordered perturbation theory, and the relevant diagrams are shown in Fig. 1. The leading $O(p^{-1})$ contribution, diagram (a), is the one-pion exchange. The other diagrams are all $O(p)$: besides relativistic correction to OPE, we have TPE, diagrams (b)-(c)-(d), vertex corrections, diagrams (e)-(f), which can be reabsorbed into a redefinition of h^1_π, and the five contact interaction from diagram (CT). Loop corrections to the contact interaction, diagrams (g)-(h) vanish, after the loop integration. The Fourier transform to coordinate space is accomplished by inserting a momentum cutoff $f_\Lambda(k) = \exp(-k^4/\Lambda^4)$ depending on the momentum transfer k, with Λ, in

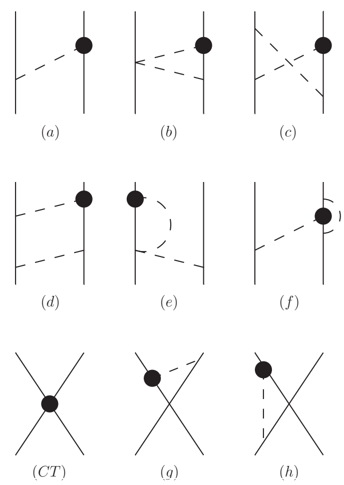

Figure 1. Diagram contributing to the PV nuclear potential up to N2LO. Only one time ordering is shown for each topology. The solid circle represent insertions of PV vertices.

the range 500-700 MeV. The resulting (local) potential depends on six unknown parameters (the weak pion-nucleon coupling constant h^1_π and the five LECs $C_{1,\ldots,5}$ of the contact interaction), and on the cutoff Λ. The intervening LECs can be constrained using the accurate measurements of the $\vec{p}-p$ longitudinal asymmetry $\bar{A}^{pp}_z(E)$ at different laboratory energies E. Indeed, using our potential, in combination with the realistic N3LO parity conserving potential of Entem and Machleidt, this observable can be expressed as

$$\bar{A}^{pp}_z(E) = a_0(E)h^1_\pi + a_1(E)C'_1 + a_2(E)C_2, \quad (1)$$

where $C'_1 = C_1 + 2C_4 + 2C_5$ and $a_i(E)$ are numerical coefficients depending only on the cutoff Λ. It turns out that the data at three different energies only constrain two of the above combinations of LECs. We therefore performed the calculations for three values of the coupling constants h^1_π in the "reasonable range" suggested by DDH. The corresponding values for C'_1 and C_2 are shown in Table 1. With the potential so constrained, we

Λ(MeV)	C'_1	C_2	$10^7 \cdot h^1_\pi$
500	-2.15516	9.98171	4.56
600	-2.69957	10.03513	4.56
700	-4.22214	10.66532	4.56
500	-1.51765	4.00256	0
600	-2.18203	4.42237	0
700	-4.68110	5.86730	0
500	-3.11142	18.9504	11.4
600	-3.47588	18.4543	11.4
700	-3.53372	17.8623	11.4

Table 1
Values of the LECs C'_1 and C_2 for three different choices of h^1_π and cutoff Λ, to reproduce the experimental values of $\bar{A}^{pp}_z$ at 45 and 221 MeV.

examined in Ref. [5] the longitudinal asymmetry in the charge-exchange reaction $^3\mathrm{He}(\vec{n},p))^3\mathrm{H}$ at cold neutron energies, which is given by [6]

$$A^{n^3\mathrm{He}}_z = a_z \cos\theta, \quad (2)$$

where θ is the angle between the outgoing proton momentum and the neutron beam direction. We computed a_z supplementing the parity conserving realistic potential by the N2LO chiral three-nucleon interaction and by our version of the PV nuclear potential. The results are shown, assuming $C_{3,4,5} = 0$, in Table 2. We have explored the sensitivity to $C_{3,4,5}$, and found it to be appreciable, of the order of 20%. Therefore this asymmetry could be useful to extract such LECs. As it is apparent from the table, the results are almost cutoff-independent. Since the cutoff-dependence gives a measure of the importance of higher order contributions, this suggests that the N2LO PV potential could be accurate enough.

Λ(MeV)	LO	full	$10^7 \cdot h^1_\pi$
500	-0.551	-0.544	4.56
600	-0.554	-0.578	4.56
700	-0.546	-0.584	4.56
500	0.000	0.044	0
600	0.000	0.034	0
700	0.000	0.009	0
500	-1.377	-1.425	11.4
600	-1.385	-1.497	11.4
700	-1.366	-1.473	11.4

Table 2
Asymmetry coefficient a_z (in units of 10^{-7}) at leading order (LO), and N2LO (full), for the different combinations of LECs and cutoff displayed in Table 1. Values of the LECs C'_1 and C_2 for three different choices of h^1_π and cutoff Λ, to reproduce the experimental values of $\bar{A}^{pp}_z$ at 45 and 221 MeV.

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