PARITY VIOLATION IN PROTON-PROTON SCATTERING *)

Augusto Barroso **) 
CERN — Geneva

ABSTRACT

The present situation regarding the parity violation in p-p scattering is briefly reviewed. Particular attention is paid to the models used in the calculation of the asymmetry at high energies.


**) Permanent address: CFN, Universidade de Lisboa, 1699 Lisboa, Portugal.
In this talk I would like to summarize the present situation regarding parity-violation in p-p scattering. The existing experimental results at low energy\(^1,2\) are well described in terms of a weak meson exchange potential\(^3\) which also explains other nuclear physics parity violating experiments\[^4\] for a review. Furthermore, the so-called Desplanques-Donoghue-Holstein (DDH)\(^3\) best values of the effective nucleon-meson weak couplings are in reasonable agreement with theoretical calculations based on the standard weak model including QCD corrections [e.g., Ref. 5].

If \(\sigma\) denote the total cross-section associated with each helicity state of the polarized incoming proton, the information about the weak interaction is contained in the asymmetry,

\[
A = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}.
\]

(1)

At low energies, i.e., below the inelastic threshold, one can either solve the two-body scattering problem exactly or one can use a distorted wave Born approximation. As I said before, the calculations are in good agreement with the data [e.g., Ref. 6].

Let me describe briefly a naive model which despite its simplicity does remarkably well. Consider the strong helicity amplitude \(\phi_1 = \langle++|T_0|++\rangle\). Adding to \(\phi_1\) the weak Born contribution \(\psi_1\) derived\(^6\),\(^7\) from an effective meson-nucleon Lagrangian, it is easy to see\(^6\) that the elastic asymmetry \(A_{el}\) is

\[
A_{el} = \frac{1}{2\sigma_{el}} \frac{\pi}{k^2} \text{Re}[\phi_1(t=0)] \int_0^\infty dt \psi_1(t) \exp\left[\frac{1}{2} \gamma t\right],
\]

(2)

where \(k\) is the c.m. momentum and \(\gamma\) is the slope parameter of the differential cross-section \(d\sigma/dt\). By a dispersion relation analysis of the scattering data the values of \(\phi_1\) at \(t = 0\) can be obtained\(^8\). Using these and \(\gamma = 1\ \text{GeV}^{-2}\) one obtains \(A_{el}\), as a function of the proton

\[^{\text{Permanent address: CFN, Universidade de Lisboa, Portugal.}}\]
lab. kinetic energy $T_L$. This is shown in Fig. 1. Besides the reasonable agreement with the data, notice that the results do not depend crucially on the value of $\gamma$. On the contrary, for $\gamma$ in the range $0.5 \text{ GeV}^{-2} \leq \gamma \leq 1.5 \text{ GeV}^{-2}$ the variation of $A_{el}$ is less than 2%.

Let me now turn to the high energy region where a recent measurement$^9$ of $A$ using a water target prompted several calculations$^7,10)-13$ of this effect. In the pioneer work of Henley and Krejs$^{10}$, as well as in some of the recent ones$^7,11$, the starting point is the calculation of the weak Born helicity amplitudes. The strong distortion is included using two basic approaches. In the first one, for each partial wave, one makes the S matrix unitary. In the second approach, the partial wave series is converted into an integral over the impact parameter $b$ and the Born amplitudes are multiplied by $\exp [iX(b)]$ where $X(b)$ is the eikonal phase shift. The comparison between these two techniques was made before$^6$ and so there is no need to be repeated here. I just
want to point out that both methods predict, at $p_L = 6 \text{ GeV/c}$, values of $A$ at least an order of magnitude smaller than the experimental result$^9$. Notice also that in the work of Tadić and myself$^7$, the neutron contribution was calculated and the two-pion exchange diagram was included. Adding coherently the proton and neutron contributions our revised$^6$ result for water is $A = 3 \times 10^{-8}$ where at the same energy the Argonne experiment$^9$ gives $(3.66 \pm 0.64) \times 10^{-8}$.

In the work of Nardulli and Preparata$^{12}$, the scattering amplitude $f$ which describes the high energy elastic scattering of a polarized nucleon off an unpolarized one is written

$$f = \bar{u}(p') A(s,t) \gamma^\mu(1 + \epsilon \gamma_5)(p + p')_\mu u(p).$$  \hspace{1cm} (3)$$

$A(s,t)$ is the pomeron amplitude and the $\epsilon$ parameter is a measure of the parity impurity in the nucleon wave function. From Eq. (3) it is straightforward to obtain

$$A = \frac{|p_L|}{E_L} \epsilon.$$  \hspace{1cm} (4)$$

With their calculated value of $\epsilon$ they$^{12}$ predicted $A = 2.13 \times 10^{-6}$ at $p_L = 6 \text{ GeV/c}$.

It is easy to see that, given an effective parity conserving meson-nucleon Lagrangian, the introduction of a parity admixture into the nucleon field $N$ amounts to the transformation

$$N \rightarrow N' = (1 + \epsilon \gamma_5)N.$$

This, in turn, generates an effective parity violating Lagrangian, $\mathcal{L}_{PV}$. Then, using this $\mathcal{L}_{PV}$ and the model that I described previously I calculated the asymmetry in the low energy region. In the upper part of Fig. 1, I show the ratio $R$ between the asymmetry $A_{el}$ calculated in this way and the one predicted on the basis of DDH$^3$ weak couplings. $R$ is within 1% constant and equal to 11 which means that the calculation of Nardulli and Preparata$^{12}$ overestimates $A_{el}$ by an order of magnitude. Recently, Donoghue and Holstein$^{14}$ have also used the same model to re-analyze some well established cases of parity-violation in nuclear physics. They$^{14}$ concluded that the values of $\epsilon$ predicted by Nardulli and Preparata$^{12}$ always overestimate the experimental results by, at least, an order of magnitude. For instance, in $^{21}$Ne the polarization $P_y$ of the 2.789 MeV $\gamma$-ray turned out to be $P_y = 0.18$ whereas the experiment$^{19}$ gives $(0.9 \pm 5.1) \times 10^{-3}$.

Since we now have another scattering experiment$^{16}$ done at $p_L = 1.5 \text{ GeV/c}$ and using the same target, one can test this model in a different way. From Eq. (4), one obtains $A(1.5 \text{ GeV/c})/A(6 \text{ GeV/c}) = 0.86$. On the other hand, the experiments$^{9,16}$ give $R \leq 0.55$ at 90% C.L.
It is fair to say that another calculation\(^{17}\) of \(A(15\, \text{MeV})\) using the Nardulli-Preparata model only overestimates the experimental value by a factor of three and not 11 as I have shown. The reason for this lies in their\(^{17}\) use of a very large value for the weak pion-nucleon coupling constant \(f_\pi\). Their\(^{17}\) value \(f_\pi = 13.5 \times 10^{-6}\) causes that the two pion contribution cancels partially the \(\rho\) and \(\omega\) exchange terms. However, it is known, both from semi-empirical analysis of nuclear physics data and from theoretical calculations that the value of \(f_\pi\) must be a factor of 20 smaller than the number quoted above. I do not have time to go into a detailed discussion of this point\(^4\) but let me just mention that a recent calculation\(^{18}\) in the framework of the standard weak model including QCD corrections gives \(f_\pi = 0.3 \times 10^{-6}\) in very good agreement with the \(SU(6)\) analyses\(^3\).

Finally, let me refer to the work of Goldman and Preston\(^{13}\). They attempted to calculate \(A\) using a quark model, i.e., the weak amplitude was given by \(W\) and \(Z\) exchange between quarks and the strong interaction amplitude was described by one gluon exchange. Besides the tree diagrams they also include one loop corrections. At the Argonne energy they predicted \(A = -10^{-7}\) which has even the wrong sign. Perhaps not surprisingly, given the drastic assumption in the description of the strong amplitude. Only calling upon the same mechanism of nucleon wave function admixture could they\(^{13}\) claim agreement with the data.

In conclusion, I would say that the only model\(^{12}\) that claims to explain the Argonne result\(^{8,9}\) is in serious difficulty to accommodate all experimental data on low energy parity conservation. On the other hand, the Los Alamos result\(^{16}\) can be understood on the basis of the conventional calculations\(^{5,12}\). Clearly further experimental and theoretical work is needed to clarify this situation.


\(^{8}\)A large \(A\) can result from the decay of longitudinally polarized hyperons. However, in Ref. 9) it is claimed that this effect was eliminated.
REFERENCES


