IC/83/228

INTERNATIONAL CENTRE FOR
THEORETICAL PHYSICS

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INTERNATIONAL ATOMIC ENERGY AGENCY

UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

1984 MIRAMARE-TRIESTE

IC/83/228

International Atomic Energy Agency

and

United Nations Educational Scientific and Cultural Organization

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PARITY VIOLATING ASYMMETRY IN HIGH ENERGY PROTON-NUCLEON SCATTERING *

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ABSTRACT

Parity violating asymmetry in high energy proton-nucleon scattering has been studied using the Glauber theory and meson exchange potential model for weak interactions. By varying the weak interaction parameters within the allowed range, we find that it is possible to get the theoretical asymmetries to agree in sign with the observed ones in $\vec{p}$-H_2O scattering at 1.5 and 6.0 Gev/c but not in magnitude which always remains much smaller.

MIRAMARE - TRIESTE

December 1983

* To be submitted for publication.

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Parity violating asymmetry in proton nucleon scattering has been observed at low and high energies [1] . There have recently been many theoretical attempts to understand these results in the quark model [2] as well as in the weak meson exchange potential model [3,4] but no clear understanding of these results has emerged [5] . The quark model calculations either fail to reproduce the results at higher energies or make use of parity admixtures in nucleon wave functions to explain these results. These models, when applied at low energies, overestimate the observed effects by an order of magnitude [6] . The potential model calculations, on the other hand, do well to explain the results at low energies, including the effects observed in low energy nuclear physics [7] , but grossly underestimate the asymmetries at high energies, even giving the wrong sign in some cases *).

In order to calculate the parity violating asymmetry, the high energy potential model calculations make use of the Gottfried-Jackson absorption model and its prescription [8] to calculate the strong distortion effects responsible for inducing the imaginary part in the otherwise real weak Born amplitude calculated in one boson exchange approximation. We note that use of any such prescription is avoided if one works in the framework of the Glauber model of high energy scattering [9] to calculate the full proton-nucleon scattering amplitude including the effects of weak, electromagnetic and strong interactions. In this model, the proton-nucleon scattering amplitude is written as

$$f_{PN}(\vec{q}) = \frac{ik}{2\pi}\int d^2b\; e^{i\vec{q}\cdot\vec{b}}\left[1-\prod_{i=1}^{3}\left(1-\Gamma_i(\vec{b})\right)\right] \qquad (1)$$

where Γ_i(b)'s are the profile functions for impact parameter b, and k is the incident momentum in the centre of mass frame. These profile functions

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*) The numerical values for the asymmetries in $\vec{p}$-H_2O scattering at p_{lab} = 1.5 and 6.0 Gev/c along with their experimental values are quoted later in Table 2.

Γ_i(b) are related to the Fourier transforms of the scattering amplitudes and are given by

$$\Gamma_{S,W,EM}(\vec{b}) = \frac{1}{2\pi ik}\int d^2q\; e^{-i\vec{q}\cdot\vec{b}}\, f_{S,W,EM}(\vec{q}) \qquad (2)$$

where $f_S(\vec{q})$, $f_W(\vec{q})$ and $f_{EM}(\vec{q})$ are the proton-nucleon scattering amplitudes for strong, weak and electromagnetic interactions.

Combining eqs. (1) and (2) we get:

$$\begin{aligned} f_{PN}(\vec{q}) = {} & f_S(\vec{q}) + f_W(\vec{q}) + f_{EM}(\vec{q}) + \frac{i}{2\pi k}\int f_W(\vec{q}\,')\, f_S(\vec{q}-\vec{q}\,')\, d^2q' \\ & + \frac{i}{2\pi k}\int f_W(\vec{q}\,')\, f_{EM}(\vec{q}-\vec{q}\,')\, d^2q' + \frac{i}{2\pi k}\int f_{EM}(\vec{q}\,')\, f_S(\vec{q}-\vec{q}\,')\, d^2q' \\ & + \left(\frac{i}{2\pi k}\right)^2 \int f_S(\vec{q}\,')\, f_W(\vec{q}\,''-\vec{q}\,')\, f_{EM}(\vec{q}-\vec{q}\,'-\vec{q}\,'')\, d^2q'\, d^2q'' \end{aligned} \qquad (3)$$

Various terms occurring in equation (3) have an obvious interpretation and the effect of distortion due to the presence of other interactions enter very naturally in this formalism. Expressions similar to equation (3) can be derived for various helicity amplitudes which are relevant for the discussion of parity nonconservation effects in proton nucleon scattering [3,4].

If $f_{PN}^{\lambda_1\lambda_2\lambda_1'\lambda_2'}(q)$ describes the scattering amplitude of two initial nucleons of helicities λ_1 and λ_2 scattering to the final nucleons of helicities λ_1' and λ_2', then the total cross section for this scattering process is related to the $\mathrm{Im}\, f_{PN}^{\lambda_1\lambda_2\lambda_1'\lambda_2'}(0)$ through the optical theorem. Special care should, however, be taken while using the optical theorem in the presence of electromagnetic interactions. There are standard procedures to do this [10], but since the effect of electromagnetic distortion is not expected to be large in parity violating asymmetries [11], we neglect it for the purpose of present calculations. Making use of the optical theorem as such, we write the parity violating asymmetry in total proton-nucleon cross section as

$$\mathcal{A}_{PN} = \frac{\mathrm{Im}\,[\, f_{PN}^{++,++}(0) - f_{PN}^{+-,+-}(0)\,]}{\mathrm{Im}\,[\, f_{PN}^{++,++}(0) + f_{PN}^{+-,+-}(0)\,]}\,, \qquad (4)$$

where $f_{PN}^{++,++}(\vec{q})$ and $f_{PN}^{+-,+-}(\vec{q})$ are the total proton nucleon scattering amplitudes for the two helicity states of the initial proton. Using various symmetry relations for the weak and strong helicity amplitudes $f_W^{\lambda_1\lambda_2\lambda_1'\lambda_2'}(\vec{q})$ and $f_S^{\lambda_1\lambda_2\lambda_1'\lambda_2'}(\vec{q})$ [4,12] and neglecting the contribution of spin flip amplitudes in strong amplitudes at high energies [3,13], the expression for the asymmetry in total cross section is written as

$$\mathcal{A}_{PN} = \frac{\mathrm{Im}\left\{ f_W^{++,++}(0) + f_W^{+-,+-}(0) + \frac{i}{2\pi k}\int \left[f_W^{++,++}(\vec{q}) + f_W^{+-,+-}(\vec{q}) \right] f_S^{++,++}(-\vec{q})\, d^2q \right\}}{2\,\mathrm{Im}\, f_S^{++,++}(0)} \qquad (5)$$

Noting further that the weak amplitudes $f_W^{++,++}(\vec{q})$ and $f_W^{+-,+-}(\vec{q})$ calculated in the Born approximation using one boson exchange approximation are real (see Eqs. (7) below), the final expression for the asymmetry is simplified and becomes

$$\mathcal{A}_{PN} = \frac{\eta}{4\pi k}\int \left[f_W^{++,++}(\vec{q}) + f_W^{+-,+-}(\vec{q}) \right] e^{-\alpha q^2}\, d^2q \qquad (6)$$

where α is the slope and η is the ratio of real to imaginary part of the spin averaged strong amplitude $f_S(\vec{q})$ evaluated at $q^2=0$. For purposes of numerical evaluations we have taken the values of η and α from the compilations of Dumbrajs and Staszel [13], Lasinski [14] and Grein and Kroll [14].

The weak amplitudes $f_W(\vec{q})$ are calculated in one boson exchange approximation using a suitable Lagrangian for the parity conserving and parity violating parts [3,4,15]. The results, in the case of proton-proton scattering, for example, are given by

$$f^{++,++}_{W,\,\rho\ \mathrm{exchange}}(q) = -\frac{k}{\pi}\, g_\rho\,(f_\rho^0 + f_\rho^1 + f_\rho^2)\left[\frac{1+\mu_V\, q^2/4k^2}{m_\rho^2 + 4k^2} + \frac{1+\mu_V\,(1-q^2/4k^2)}{m_\rho^2+4k^2-q^2} \right]$$

$$f^{++,++}_{W,\,\omega\ \mathrm{exchange}}(q) = -\frac{k}{\pi}\, g_\omega\,(f_\omega^0 + f_\omega^1)\left[\frac{1+\mu_S\, q^2/4k^2}{m_\omega^2 + 4k^2} + \frac{1+\mu_S\,(1-q^2/4k^2)}{m_\omega^2+4k^2-q^2} \right]$$

$$f^{+-,+-}_{W,\,\rho\ \mathrm{exchange}}(q) = f^{+-,+-}_{W,\,\omega\ \mathrm{exchange}}(q) = 0 \qquad (7)$$

The values of various coupling constants $g_{\rho,\omega}$, $f^{0,1}_{\rho,\omega}$ and f^2_ρ are given in Table 1 along with their allowed range of variation. Similar expressions are obtained for ρ and ω exchanges in the case of proton neutron scattering. In this case there is an additional term coming due to the pion exchange diagrams which contributes to the proton neutron charge exchange scattering. The charge exchange scattering in the backward direction contributes to the elastic proton neutron cross section in the forward direction. The contribution of these pion exchange diagrams is expected to be small at least by an order of magnitude and we do not include them in the present calculations [3,4] *).

Using the weak amplitudes given in equation (7) the asymmetry is calculated from equation (6). The numerical results for the parity violating asymmetry in proton-proton and proton-neutron scattering are shown in Figs. 1 and 2 for two sets of weak interaction parameters. The dashed

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*) The pion exchange contribution as calculated by Barroso and Tadic [4] makes use of eikonalizing the partial wave expansion of helicity amplitudes in the backward direction. The neglect of a crucial phase factor in achieving this eikenolization is, in our view, not justified.

curves refer to the Desplanques-Donoghue-Holstein (DDH) best values [4,15] and the dotted curves refer to the same set of parameters but using $f_{\rho}^{o} = -1.14$ and $f_{\omega}^{o} = 0.5$. (see Table 1). The error bars indicate the uncertainly due to η which are poorly determined specially around 1.5 GeV/c. Curves are drawn for visual guidance.

The change in sign in the asymmetry around 1.5 GeV/c is directly related to the change of sign of η around these energies. The individual contributions of ρ and ω exchanges seem to compete against each other depending upon the values of the weak interaction parameters used and affect, in some cases, the change of sign in asymmetriae. The asymmetries in general are sensitive to the choice of weak interaction parameters, and this sensitivity is more in the case of proton neutron scattering than proton proton scattering. The smaller asymmetries at higher energies, in both cases, are caused mainly by the decrease in the real part of the strong amplitudes and also due to the weak amplitude which becomes smaller at higher energies as implied by equation (7). In general, the asymmetries in proton neutron scattering are an order of magnitude smaller than those in proton proton scattering if DDH best values of weak interaction parameters (set 1) are used. This is in agreement with the results of Barroso and Tadic [4] but numerically our results are different than theirs specially for proton neutron scattering.

In order to compare our results with the experimental values which are available for $\vec{p}$-H_2O scattering at p_{lab} = 1.5 and 6.0 Gev/c, we coherently add the proton proton and proton neutron asymmetries as done by Barroso and Tadic [4]. Our results along with the results of other calculations are presented in Table 2, where a comparison with the experimental values can be made. It does not seem likely that the observed effects can be explained in weak meson exchange potential model with our present knowledge of weak interaction parameters. Changing the weak interaction parameters from the DDH best values one can reproduce the correct sign for asymmetries at both energies (set 2), but the magnitudes still remain smaller. Moreover this change in parameter values may upset the good agreement achieved, at low energies, in potential model calculations.

The discrepancy between the observed and the theoretical results may be more than estimated here if nuclear effects are properly taken into account. Keeping in mind the different energy dependence of asymmetries in the case of proton proton and proton neutron scattering and their sensitivity to the weak interaction parameters, the assumption of taking $\mathcal{A}_{pp} = \mathcal{A}_{pn}$ as done by Frankfurt and Strikman [16] to calculate the nuclear screening effects, does not seem justified. The formalism presented here can be very useful in making reliable estimates of the effects of various nuclear and electromagnetic distortions on the parity violating asymmetries in elastic as well as total cross sections in proton nucleus scattering at high energies.

ACKNOWLEDGMENTS

We are thankful to Professor Abdus Salam, the International Atomic Energy Agency and UNESCO for hospitality at the Internationale Centre for Theoretical Physics, Trieste. We would also like to thank Prof. G. Furlan for his interest in this work.

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TABLE 1

Weak interaction coupling constants

Meson Exchanged	g	$f^0 \times 10^6$	$f^1 \times 10^6$	$f^2 \times 10^6$
ρ	2.79	1.14 (-1.14→3.08)	.019 (0→.039)	.194 (.155→.255)
ω	8.37	.190 (-.57→1.03)	.114 (.076→.19)	

Values in brackets give the allowed range of variation. See ref. [4]

TABLE 2

Results for Asymmetries in $\vec{p}$-H_2O scattering

P_{lab} (Gev/c)	Set 1 $\times 10^7$	Set 2 $\times 10^7$	BT[+] $\times 10^7$	HK1[++] $\times 10^7$	HK2[++] $\times 10^7$	Experiment $\times 10^7$
1.5	-2.01	.44	-2.24	-1.32	-.17	6.6 ± 3.2
6.0	.49	.39	+ .45	- .91	+.31	26.5± 6.0

\+ Calculated from Ref. [4] neglecting pion exchange contribution.

++ Calculated from Ref. [3] neglecting pion exchange contribution.

FIGURE CAPTIONS

Fig. 1 Parity violating asymmetries in proton proton scattering. The dashed curve refers to the DDH best values of weak interaction parameters (see Table 1) Set. 1. The dotted curve refers to the weak interaction parameters (set 2): $f_g^0=-1.14$ and $f_\omega^0= 0.5$. The error bars show the uncertainty in asymmetries due to poor determination of η . Curves are drawn for visual guidance.

Fig. 2 Same as Fig. 1 for proton -neutron scattering.

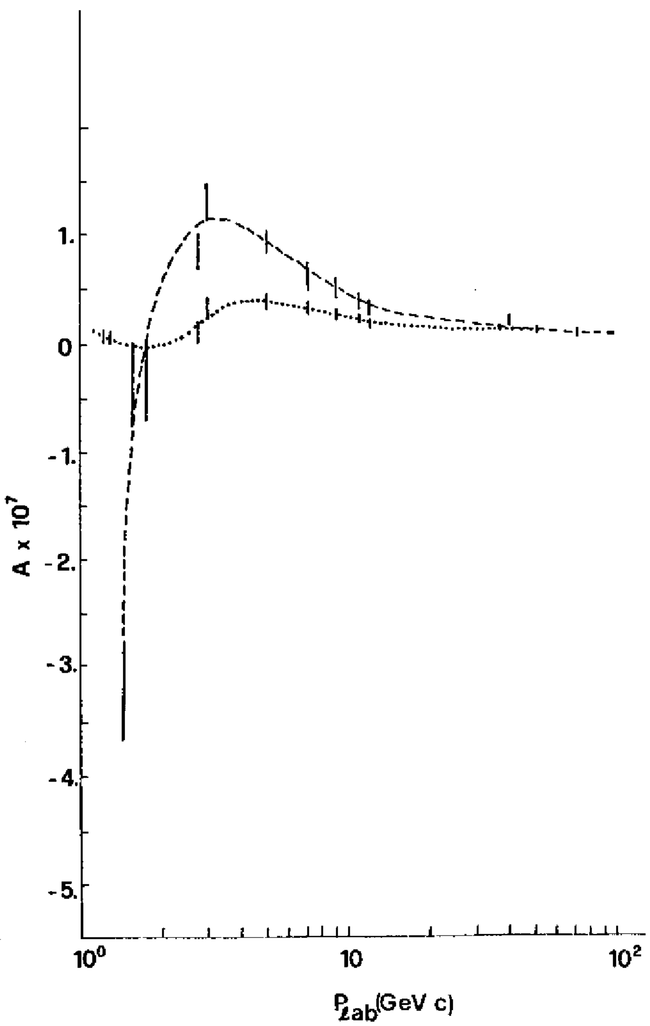
1.
0
-1.
-2.
-3.
-4.
-5.
A x 10^7
10^0
10
10^2
P_lab(GeV c)

Fig.1

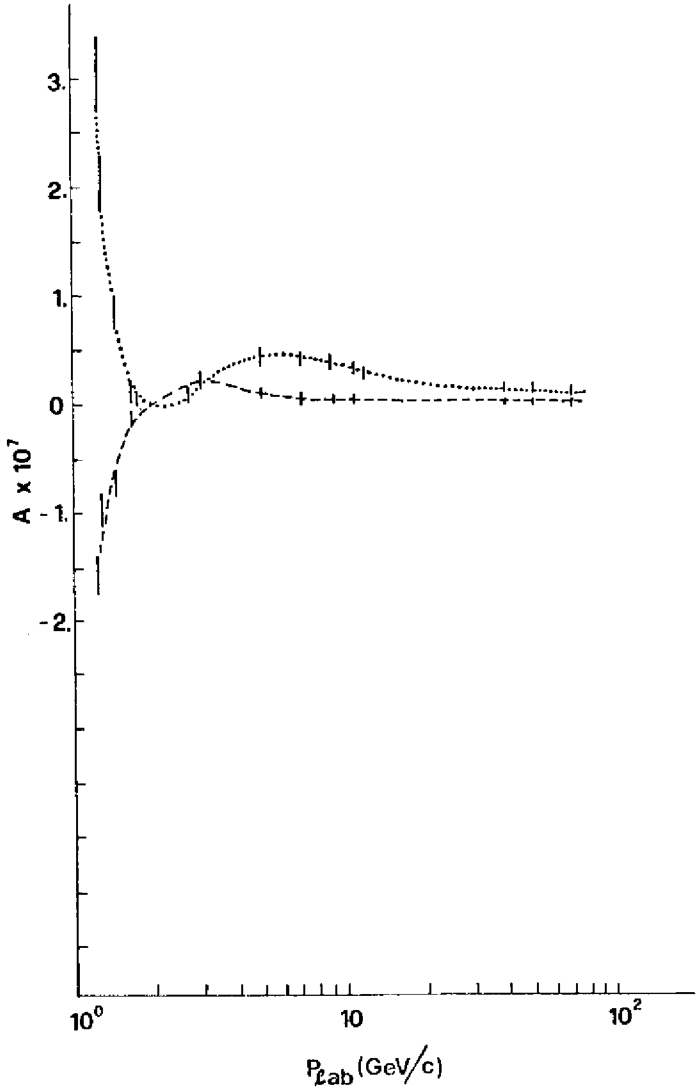
3.
2.
1.
0
-1.
-2.
A x 10^7
10^0
10
10^2
P_lab (GeV/c)

Fig.2