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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

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V.K. Samaranayake

INTERNATIONAL ATOMIC ENERGY AGENCY

UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

1977 MIRAMARE-TRIESTE

IC/77/53

International Atomic Energy Agency
and
United Nations Educational Scientific and Cultural Organization

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DETERMINATION OF THE PION-NUCLEON COUPLING CONSTANT *

V.K. Samaranayake **
International Centre for Theoretical Physics, Trieste, Italy.

ABSTRACT

Forward dispersion relations are used to determine the pion-nucleon coupling constant and S-wave scattering lengths using a least squares fit with additional parameters introduced to take account of the uncertainties in the calculation of dispersion integrals. The values obtained are: $f^2 = (78.0 \pm 2.1)\cdot10^{-3}$, $a_1-a_3 = (272.4 \pm 12.3)\cdot10^{-3}$, $a_1 + 2a_3 = (15.1 \pm 10.4)\cdot10^{-3}$.

MIRAMARE - TRIESTE
June 1977

* To be submitted for publication.

** On leave of absence from University of Sri Lanka, Colombo Campus, P.O. Box 1490, Colombo, Sri Lanka.

INTRODUCTION

Several authors have published values for the pion-nucleon coupling constant during the past few years but there is still much disagreement among the results obtained using different methods and data, as can be seen from Table I. The calculation of Samaranayake and Woolcock (1972) was performed before the experimental data of Carter et al. (1973) were available but the total cross-section data of the same group (Carter et al. 1971) were used. Bugg et al. (1973) have used their own data (Carter et al. 1973) in calculating f^2 by taking a weighted average of values obtained from fixed t dispersion relations at different values of t, using the B^+ amplitude. They also mention that the use of forward dispersion relations for the D amplitude resulted in a shallow minimum near $f^2 = 0.08$. Hence they have used the D amplitude only to calculate the S-wave scattering lengths inserting the value of f^2 obtained from the B^+ amplitude. Woolcock (1974) has shown that the above calculation should be corrected to give a smaller value. Ayed and Bareyre (1973) use a Saclay phase-shift analysis to obtain a still smaller value for f^2. Hite et al. (1975) use an interior dispersion relation for the B^+ amplitude to calculate f^2. They use two sets of data: the CERN phase shifts (Almehed 1972) and a modified version of the phase shifts of Carter et al. (1973). They find that the B^- amplitude does not yield satisfactory results. In their calculation, the integrals in the unphysical region are not calculated but are assumed to be a smooth function and are approximated by a Taylor series expansion which is incorporated into the fits. They fit the data with equal weights, but a weighted average of the resulting values of f^2 is quoted as the final result.

f^2	Method of calculation	Reference
$0.0810 \pm \begin{matrix}0.0030\\0.0040\end{matrix}$	Recommended value	Ebel 1971
0.0763 ± 0.0020	FDR for $D^\pm$	Samaranayake & Woolcock 1972
0.0742 ± 0.0013	FDR for B^+	Ayed 1973
0.0790 ± 0.0010	Fixed t DR for B^+	Bugg et al. 1973
0.0784 ± 0.0010	Correction to above	Woolcock 1974
0.0795 ± 0.0010	Interior DR with modified CBC data	Hite et al. 1975
0.0815 ± 0.0015	Interior DR with CERN data	Hite et al. 1975

Table I

Recent calculations of f^2

In the present determination of f^2 we use forward dispersion relations fitted with two additional parameters to account for discrepancies in the dispersion integrals in the low-energy and unphysical regions. The resulting values of f^2 and other parameters are then used to calculate the S-wave scattering lengths.

METHOD AND DATA

The dispersion relations for $D^{\pm}(\omega)$ defined in Samaranayake and Woolcock (1972) are used in this calculation. Throughout the paper the notation used is again that of Samaranayake and Woolcock (1972). The dispersion relations

$$D^{(+)}(\omega) = C + 2f^2\omega_n\,(\omega^2 - \omega_n^2)^{-1} + I^{(+)}(\omega)\ ,$$

$$D^{(-)}(\omega) = 2f^2\omega\,(\omega^2 - \omega_n^2)^{-1} + I^{(-)}(\omega)\ ,$$

where

$$I^{(+)}(\omega) = \frac{\omega^2}{\pi M}\int_{\omega_n}^{\mu}\frac{d\omega' W(\omega') A_-^{CM}(\omega')}{\omega'(\omega'^2-\omega^2)} + \frac{\omega^2}{2\pi^2}\,P\int_{\mu}^{\infty}\frac{d\omega'(\omega'^2-\mu^2)^{1/2}\,\sigma^{(+)}(\omega')}{\omega'(\omega'^2-\omega^2)}\ ,$$

$$I^{(-)}(\omega) = \frac{\omega}{\pi M}\int_{\omega_n}^{\mu}\frac{d\omega' W(\omega') A_-^{CM}(\omega')}{\omega'^2-\omega^2} + \frac{\omega}{2\pi^2}\,P\int_{\mu}^{\infty}\frac{d\omega'(\omega'^2-\mu^2)^{1/2}\,\sigma^{(-)}(\omega')}{\omega'^2-\omega^2}\ ,$$

are rewritten in the form:

$$\mp\omega\ \left[D_{\pm}(\omega) - I_{\pm}(\omega)\right] = 2f^2\ \left[1 \mp \frac{\omega_n}{\omega\pm\omega_n}\right] \mp C\omega\ ,$$

with

$$I_{\pm}(\omega) = \mp\frac{\omega}{\pi M}\int_{\omega_n}^{\mu}\frac{d\omega' W(\omega') A_-^{CM}(\omega)}{\omega'(\omega'\pm\omega)} + \frac{\omega}{4\pi^2}\,P\int_{\mu}^{\infty}\frac{d\omega'(\omega'^2-\mu^2)^{1/2}}{\omega'}\left[\frac{\sigma_{\pm}(\omega')}{\omega'-\omega} - \frac{\sigma_{\mp}(\omega')}{\omega'+\omega}\right].$$

The dispersion integrals $I^{(\pm)}$ were calculated as in Samaranayake and Woolcock (1972) and the contribution from the unphysical region and effects of charge exchange scattering were included. The high-energy contribution was corrected using the parametrization

$$\sigma^{(+)} = 14.4 + 1.56\,\ell n\,p + 29.4\,p^{-0.57}\ ,\ \sigma^{(-)} = 2.62\,p^{-0.43}$$

of Hendrick et al. (1975). The changes to $I^{\pm}(\omega)$ in the interval 10 GeV to infinity were:

$I^{(+)}(\mu)$ changed from $0.840.10^{-3}$ to $0.857.10^{-3}$

$I^{(-)}(\mu)$ changed from $0.540.10^{-2}$ to $0.570.10^{-2}$.

Although the contributions from the unphysical region were included as mentioned earlier, we introduce two additional parameters to account for the discrepancies in the integrals in the low-energy and unphysical regions by writing

$$I_{\pm}(\omega) = I_{\pm}^{c}(\omega) \mp \omega\Delta^{\pm}\ ,$$

where $I_{\pm}^{c}$ denotes the calculated values of the integrals. The dispersion relations can now be written as:

$$\mp\omega\left[D_{\pm}(\omega) - I_{\pm}^{c}(\omega)\right] = 2f^2\ \left[1 \mp \frac{\omega_n}{\omega\pm\omega_n}\right] \mp C\omega + \omega^2\Delta_{\pm}\ ,$$

and calculated values of $D_{\pm}(\omega)$ and $I_{\pm}(\omega)$ can be used in a least squares fit with f^2, C, Δ_+ and Δ_- as parameters.

Fits were made using several combinations of data and the results are listed in Table II. The CERN data points discarded in the calculation of Samaranayake and Woolcock (1972) were tried again and the 142 and 165 MeV data points were used, the others being discarded as earlier. The 194.3 MeV data point of the Carter (1973) phase shifts was also discarded as it contributed more than 6 to S, the weighted sum of squares of residuals. Thirteen different combinations of the four data sets a,b,c,d were used in the least squares fits first with only f^2 and C as parameters and then with all four parameters.

RESULTS AND CONCLUSIONS

The results obtained, as can be seen in Table II, are as varied as those of previous authors appearing in Table I. As we have allowed two parameters to account for the discrepancies in the dispersion integrals, our errors are larger than those of some of the previous calculations.

The four parameter fit gives a better fit than that with two parameters in all cases except data set d, which does not have a sufficiently large number of data points to give realistic results for the four parameter fit. In the two parameter fit, the CERN and Carter data taken by themselves give values for f^2 which are very different from each other and very much lower than the recommended value (Ebel et al. 1971). The inclusion of the very low energy data (data set c) considerably increases the value of f^2. The four parameter fit increases the value of f^2 and here again the very low-energy data play a very noticeable role. More experimental data in the region below 100 MeV are needed if we are to improve on these results.

We are not in a position to select one data set as giving better results than another. We feel that the present situation is best described by the combination of all four data sets (a+b+c+d) and quote the values obtained for this combination as our final result:

$$f^2 = (78.0 \pm 2.1)\cdot 10^{-3},$$

$$C = (-99.7 \pm 3.5)\cdot 10^{-3},$$

$$\Delta_+ = (1.8 \pm 1.2)\cdot 10^{-3},$$

$$\Delta_- = (-4.5 \pm 1.6)\cdot 10^{-3},$$

$$S = 106.2 \text{ for } 106 \text{ points}.$$

The above values were then used to evaluate the S-wave scattering lengths. The integrals $I^{\pm}(\mu)$ evaluated in Samaranayake and Woolcock (1972) were corrected for the high-energy contribution to give

$$I^{c(+)}(\mu) = 117.0\cdot 10^{-3}, \quad I^{c(-)}(\mu) = -49.3\cdot 10^{-3},$$

and these in turn were corrected using the values of $\Delta_{\pm}$ to give

$$I^{(+)}(\mu) = (115.7 \pm 2.0)\cdot 10^{-3}, \quad I^{(-)}(\mu) = (-52.4 \pm 2.0)\cdot 10^{-3}.$$

The results for $D^{\pm}(\mu)$ and the scattering lengths are:

$$D^{(+)}(\mu) = (0.058 \pm 0.040)\cdot 10^{-3},$$

$$D^{(-)}(\mu) = (1.043 \pm 0.047)\cdot 10^{-3},$$

$$a_1 - a_3 = (272.4 \pm 12.3)\cdot 10^{-3},$$

$$a_1 + 2a_3 = (15.1 \pm 10.4)\cdot 10^{-3}.$$

Table II

data set	f^2	C	S	number of data points
a	0.0754 ± 0.0022 0.0835 ± 0.0042	-0.1022 ± 0.0028 -0.1211 ± 0.0100	39.3 32.7	34
b	0.0712 ± 0.0091 0.0802 ± 0.0014	-0.1280 ± 0.0037 -0.1444 ± 0.0103	32.3 30.2	55
d	0.0663 ± 0.0047 0.0498 ± 0.0213	-0.1035 ± 0.0043 -0.1504 ± 0.0380	7.3 6.1	12
a+b	0.0761 ± 0.0021 0.0773 ± 0.0023	-0.1078 ± 0.0025 -0.0990 ± 0.0038	101.4 87.6	89
a+c	0.0769 ± 0.0020 0.0842 ± 0.0038	-0.1036 ± 0.0028 -0.1226 ± 0.0094	46.2 37.8	39
a+d	0.0753 ± 0.0019 0.0807 ± 0.0038	-0.1013 ± 0.0024 -0.1150 ± 0.0085	47.9 43.3	46
b+d	0.0625 ± 0.0045 0.0637 ± 0.0054	-0.1166 ± 0.0032 -0.1062 ± 0.0062	55.9 52.0	67
c+d	0.0767 ± 0.0044 0.0718 ± 0.0168	-0.1040 ± 0.0053 -0.1412 ± 0.0404	16.5 11.9	17
a+b+c	0.0762 ± 0.0019 0.0779 ± 0.0021	-0.1089 ± 0.0024 -0.1012 ± 0.0036	106.7 94.5	94
a+c+d	0.0767 ± 0.0019 0.0817 ± 0.0035	-0.1023 ± 0.0024 -0.1169 ± 0.0082	55.0 48.5	51
a+b+d	0.0747 ± 0.0020 0.0764 ± 0.0022	-0.1064 ± 0.0022 -0.0980 ± 0.0035	112.9 99.3	101
b+c+d	0.0705 ± 0.0034 0.0742 ± 0.0041	-0.1168 ± 0.0069 -0.1094 ± 0.0064	63.2 60.7	72
a+b+c+d	0.0759 ± 0.0018 0.0780 ± 0.0021	-0.1070 ± 0.0022 -0.0997 ± 0.0035	118.4 106.2	106

Results obtained from the least squares fits. For each data set, the first line of values are from the two parameter fit (1) and the second from the four parameter fit (2). The data sets are (a) Lovelace (1968) 215-270 MeV, (b) Lovelace (1968) 310-1935 MeV, (c) Fischer and Jenkins (1959) 5-229 MeV, (d) Carter et al. (1973) 885-291 MeV (see text).

The value for a_1-a_3 is consistent with the previous calculations but the result for $a_1 + 2a_3$ gives a positive value which remains positive even within the errors. This contradicts most calculations performed earlier but is still within the errors quoted by Ebel (1971). This value is dependent on the parameter C and is sensitive to the data used. Use of the two parameter fit value of C will of course reduce the value of $a_1 + 2a_3$. Here again we need more accurate low-energy data in order to obtain an accurate value for this parameter.

In this paper we have shown that the parameters are sensitive to the dispersion integrals and that a better fit to the data can be obtained by introducing the two additional parameters to account for discrepancies in the integrals. This has resulted in our obtaining a new set of parameters, which can be used until more accurate experimental data are available for a detailed study.

ACKNOWLEDGMENTS

The author would like to thank Professor Abdus Salam, the International Atomic Energy Agency and UNESCO for hospitality at the International Centre for Theoretical Physics, Trieste. Thanks are also due to Professor L. Bertocchi for critical reading of the manuscript.

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