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CONSTRAINED PHASE ANALYSIS OF PION-DEUTERON SCATTERING*

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ABSTRACT

A relativistic three-body theory of the $NN\pi$ system is applied to predict πD elastic scattering. Phase shifts and inelastic parameters are compared with those of a multiple scattering calculation.

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In principle, the πD system can play a unique role in our efforts to better understand nuclear dynamics. Thus, by confronting "exact" three-body calculations with experiment, one may probe the fundamental πN interaction (taken as input), and resolve (possibly crucial) formal questions regarding the proper inclusion of relativistic effects. One may also test and improve more approximate methods, such as multiple scattering (MS) techniques, for applications to heavier nuclei. In fact, calculations reported to date [1] look quite promising, and have already yielded valuable information with respect to optimizing the MS approach [2]. Ultimately, however, such a program will clearly be limited by the inherent sensitivity of the system. In this article we focus on two aspects of this problem. We show that differential cross sections for πD elastic scattering may (1) be accurately predicted in a model-independent way by fitting parameters to other, more sensitive, experiments, and (2) may be generated with equal success by three-body and MS techniques, despite quite different physical assumptions <u>and</u> resulting πD phase parameters.

The considerations noted above have stimulated a number of three-body calculations of πD scattering, based either on the nonrelativistic Faddeev theory [1], or its relativistic generalizations [3]. The latter are clearly to be preferred, and permit one (in principle) to correctly account for absorption, as well as purely kinematical effects. However, the equations themselves are far from unambiguous, and have not been notably successful in a number of previous applications [4]. Also, all Faddeev-like calculations to date share a common defect in that they are based on separable off-shell amplitudes (a highly questionable assumption). In this work, we have instead chosen to characterize these uncertainties in terms of free parameters fitted to <u>other</u> types of experimental data. In this way, we have generated πD phase shifts and absorption parameters for comparison both with the elastic data, and with specific dynamical models (as we shall show, the actual data are not wholly suitable for this purpose).

In order to achieve the flexibility demanded by this program, we have employed the covariant boundary condition formalism (BCF) developed by one of us [4]. As in the Faddeev approach, this requires one to solve a set of one-variable integral equations which couple the various asymptotic channels. However, the BCF differs in that the kernel is written $K=K_S+A$, where K_S is a specified singular operator uniquely determined by the phase shifts (πN, NN), and A is a smooth residual operator characterizing everything else (off-shell structure, three-body forces, relativistic effects). Since A may be varied freely, this method is highly efficient for exploring the full range of specifically three-body effects, and has been successfully applied to a wide variety of three-body problems, including the relativistic 3π system [4, 5]. Details, earlier references, and the particular A parametrization employed here are given in a recent article concerning other aspects of this calculation [6]. Here we note that the πN phases used in the BCF were taken from [7], and that the principal omission was the absence of an explicit deuteron d-state (included in the MS calculation). However, the effect of missing channels is largely compensated by the energy-dependent parametrization of A [6].

Applying the BCF to the NNπ system, we calculated the full set of physical amplitudes for the reactions NN $\rightarrow$ NN, NNπ, πD ($T_L \leq 800$ MeV), and πD $\rightarrow$ πD, NNπ, NN ($T_L \leq 256$ MeV), in the J^P states (1^-, 0^+, 1^+, 2^+) corresponding to the πD s- and p-waves. The A parameters were chosen so as to provide an excellent fit to NN elastic scattering below 400 MeV in the associated partial-waves ($^1S_0$, $^3P_1$, $^1D_2$), and to $\sigma(pp \rightarrow \pi^+D)$ in the range 400-800 MeV [6]. Predictions were thus generated for the πD elastic amplitudes; results for the

δ, η parameters are illustrated in fig. 1. The value of the dominant 2^+ wave at 47.7 MeV (6^o) agrees precisely with the result of A. W. Thomas [1], while the other (small) waves are in reasonable qualitative agreement. However, it should be noted that at such low energies the πD phases are extremely sensitive to the input πN phases. As a general feature of these results, we observe the rapid variation and change of sign of all waves, except 0^+, in the region of the P_{33} resonance. This is associated with a rapid decrease in η, corresponding to the absorption mechanism $\pi D \rightarrow N\Delta$.

In Table I we compare the values of the phase shifts (δ) and reflection coefficients (η) for these partial-waves with those obtained in a MS calculation reported earlier [2]; the latter corresponds to a Faddeev-like prescription for single and double scattering, but with simpler off-shell behavior. In this table, the incident pion energy ranges from 85 to 256 MeV, and corresponds to experiments made on πD elastic differential cross sections. It is interesting to observe how strongly the two δ, η sets differ, although they produce cross sections which are remarkably similar (cf., fig. 2). Specifically, we note the following regarding these phases: (1) the 0^+ wave is extremely weak in the BCF calculation, while in the MS calculation it is the strongest, also showing strong inelasticity. This curious result agrees with earlier work [8], in which it was shown that the series generated by iterating the three-body equation does not converge in this state. (2) For the other two p-waves (1^+, 2^+), the two methods agree qualitatively at 85 and 142 MeV, but disagree remarkably in the region of the P_{33} resonance. It is interesting that in the BCF calculation, with a slight change in the A parameters, it is possible to shift the 2^+ phase to a form which rises sharply through 90^o near 200 MeV (instead of falling through 0^o). This is related to the fact that $\eta \simeq 0$ at that energy. The 90^o type of phase behavior was found to be correlated with larger back-angle differential cross sections at 182 MeV. (3) For increasing energies above the resonance, the methods tend to converge in all of the states shown; this trend is also apparent in the differential cross sections.

The MS approach possesses a great practical advantage, in that it explicitly sums the many partial waves required to successfully describe πD scattering at several hundred MeV. On the other hand, our calculation (and previous work [1]) has shown that it is inadequate in the small angular momentum states, where the pion may penetrate sufficiently to interact simultaneously with both nucleons. Thus, it would seem most efficient to utilize the full three-body approach in calculating the s- and p-waves, and to describe the peripheral scattering by MS techniques. We have adopted this method in computing the differential cross sections at 85, 142, 182, 224 and 234.4 MeV. Representative results at 85 and 182 MeV are shown in fig. 2, where the pure MS cross section is also shown for comparison. In general, except at the extreme backward angles at 182 (and 234.4) MeV, one would need much better data to distinguish the two.

It would thus appear quite difficult to judge dynamical models (or computational techniques) on the basis of the elastic data alone. Indeed, the BCF result suggests that improved <u>inelastic</u> data would prove much more valuable for that purpose. A noteworthy exception to this rule is the situation above 200 MeV, where both of our methods converge and fail to reproduce the apparent flattening of the cross sections for $\theta_L \geq 90^o$. As yet we can offer no explanation of this phenomenon.

References

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TABLE I

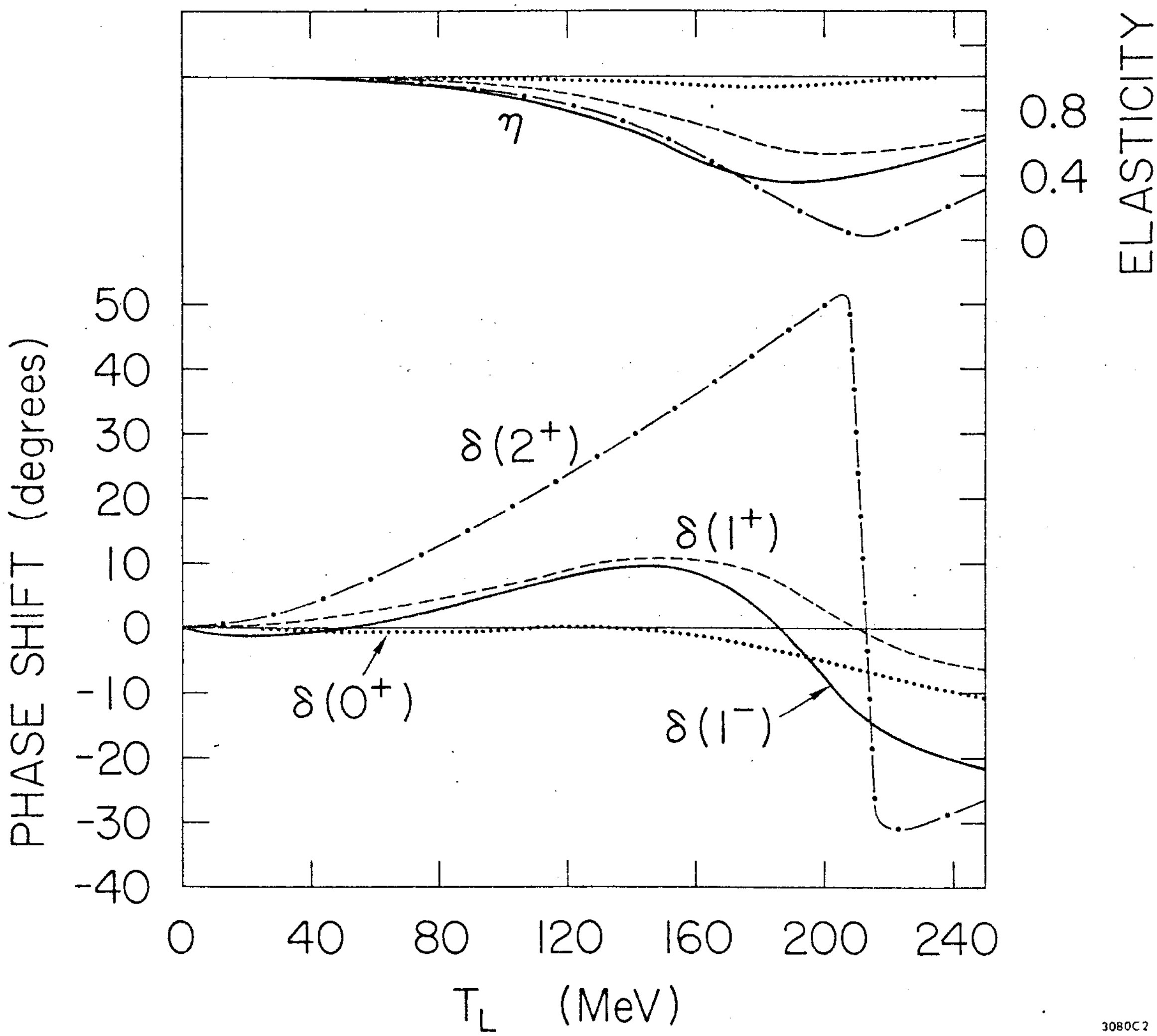
Phase shifts δ (in degrees) and elasticity η for the πD s- and p-waves, comparing multiple scattering (MS) and three-body (3b) results. T_L is the incident meson kinetic energy in the lab system.

T_L (MeV)	δ(MS)	δ(3b)	η(MS)	η(3b)	δ(MS)	δ(3b)	η(MS)	η(3b)
		($J^P = 1^-$)				($J^P = 0^+$)		
85	- .6	4.8	.92	.89	7.3	- .2	.67	.99
142	1.3	10.5	.71	.58	16.5	- .2	.13	.97
182	- 5.7	1.9	.49	.28	-43.1	- 2.9	.42	.94
224	-18.0	-23.0	.55	.40	-33.7	- 7.9	.78	.99
234	-19.6	-25.1	.58	.45	-31.3	- 9.0	.83	1.00
256	-20.5	-26.5	.64	.56	-26.7	-10.9	.90	1.00
		($J^P = 1^+$)				($J^P = 2^+$)		
85	5.6	5.0	.80	.98	6.8	13.8	1.09	.94
142	7.5	10.5	.41	.80	19.1	29.6	.94	.68
182	-21.5	8.3	.34	.57	28.3	43.8	.51	.32
224	-24.2	- 3.2	.65	.55	2.1	-30.2	.18	.09
234	-23.5	- 4.9	.70	.58	- 9.1	-28.7	.21	.17
256	-21.2	- 6.7	.78	.64	-17.4	-25.6	.32	.27

Figure Captions

1. Elastic πD phases and absorption coefficient (η) for the BCF calculation described in the text.

2. Differential cross sections for πD elastic scattering at 85 and 182 MeV. The solid (dashed) curves give the BCF (MS) results.



ELASTICITY
0.8
0.4
0
η
PHASE SHIFT (degrees)
50
40
30
20
10
0
-10
-20
-30
-40
δ(2+)
δ(1+)
δ(0+)
δ(1−)
0
40
80
120
160
200
240
T_L (MeV)
3080C2

Fig. 1

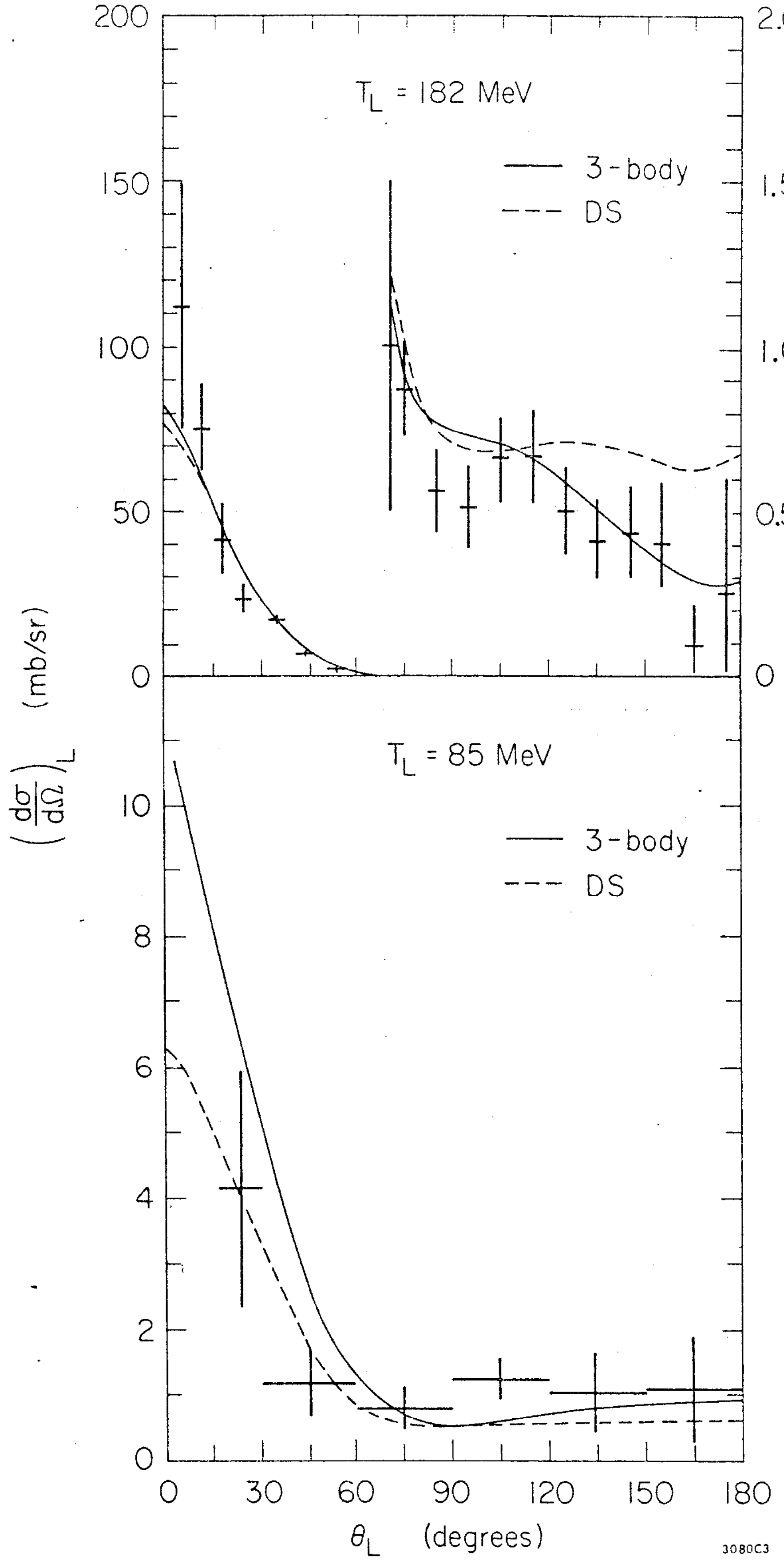

200
150
100
50
0
2.0
1.5
1.0
0.5
0
T_L = 182 MeV
3-body
DS
T_L = 85 MeV
3-body
DS
10
8
6
4
2
0
$\left(\frac{d\sigma}{d\Omega}\right)_L$ (mb/sr)
0
30
60
90
120
150
180
θ_L (degrees)
3080C3

Fig. 2