Exact Three-Body Calculations of the Proton-Deuteron Elastic Scattering from 2.5 to 22.5 MeV

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Calculation of proton-deuteron (pd) scattering represents one of the most challenging remaining tasks in few-body nuclear physics. The interest arises from two sources. First, the richness and precision of the available experimental data on many observables which to compare with, is certain to lead to more stringent tests of nuclear potential models than neutron-deuteron (nd) scattering with its much smaller and much less precise data base. Secondly, the necessity to include the Coulomb interaction in a way that is both mathematically correct and practical has been, and still is, one of the outstanding theoretical tasks. Of the several approaches that have been proposed to take into account Coulomb interactions in charged composite particle reactions, only two have reached the status to permit concrete numerical calculations. The most obvious one, namely to work with the Schrödinger [1] or equivalently differential Faddeev-Merkuriev equations [2] in coordinate space, requires knowledge of the complete boundary conditions, in order to guarantee uniqueness of the solution. Above the breakup threshold the complete boundary condition to be imposed in the region where all three particles eventually become asymptotically free [3] has, to our knowledge, not yet been implemented satisfactorily in any solution scheme. Based on momentum-space three-body Faddeev or, their modification, Alt-Grabberger-Sandhas (AGS) [5] equations, mathematically well defined integral equations for charged-composite particle reactions have been derived for two cases. Recently we have communicated the first successful calculation of proton-deuteron scattering observables for the Paris potential using this approach [6, 7]. Now we completed the work getting the results for many more energies and comparing them with experimental data. For a more detailed comparison with experimental data, in particular for polarization observables, we have performed calculations with the realistic Paris potential. In Fig. 1 we present differential cross sections for three proton laboratory energies, 5, 10 and 18 MeV. Inspection reveals that very good agreement with the experimental data of Sagara et al. [8] and of Sperison et al. [9] is achieved except at the lower energies where our calculations slightly overestimate the data. For the analyzing powers the reproduction of the data is much less satisfactory. In particular, as Fig. 2 shows the underestimation of the maximum of the vector analyzing power. That is, the so-called the A_y-puzzle which has been with us for a long time in neutron-deuteron scattering is also present in the pd reaction as has already been noted in [1]. But it appears that the failure of the theory to reproduce the experimental maximum disappears at higher energies, at the expense of an increasing discrepancy in the minimum around 100 degrees. In Ref. [8] it was pointed out that apparently the magnitude of the experimental differential cross section minimum differed appreciably from theoretical results. In fact, the relative difference $)_{\min}=$ $(\sigma^{\min}_{theor} - \sigma^{\min}_{\exp}) / \sigma^{\min}_{\exp}$ was found to be rather large and positive at low energies, to change sign around 5 MeV and to become negative large at higher energies, reaching -25% at 18 MeV, a behavior the explanation of which seems to be very difficult. This discrepancy is called 'Sagara discrepancy'. In Fig. 3 we present the relative difference)$_{min}$ for the cross section minimum between our theoretical results and the data of Ref. [8]. Inspection reveals that even with a correct description of the Coulomb repulsion between the protons the 'Sagara discrepancy' survives, albeit with greatly reduced overall magnitude as compared to the calculations with improper account of the Coulomb interaction. In addition, the percentage excess in)$_{min}$ has become only rather weakly dependent on energy in the range considered (from 9.3% at 5 MeV to 6.3% at 18 MeV), in contrast to the original estimates [8]. It is interesting to note that for all energies considered, our calculations yield a larger cross section minimum than experiment, i.e.,)$_{min}$ > 0. However, before drawing any conclusions about the origin of this overestimation it should be kept in mind that in particular the cross section minimum is very sensitive to the details of the nuclear force model. Hence, it could well be that in calculations using higher-rank and thus better, approximations of the Paris potential, the remaining difference even disappears.

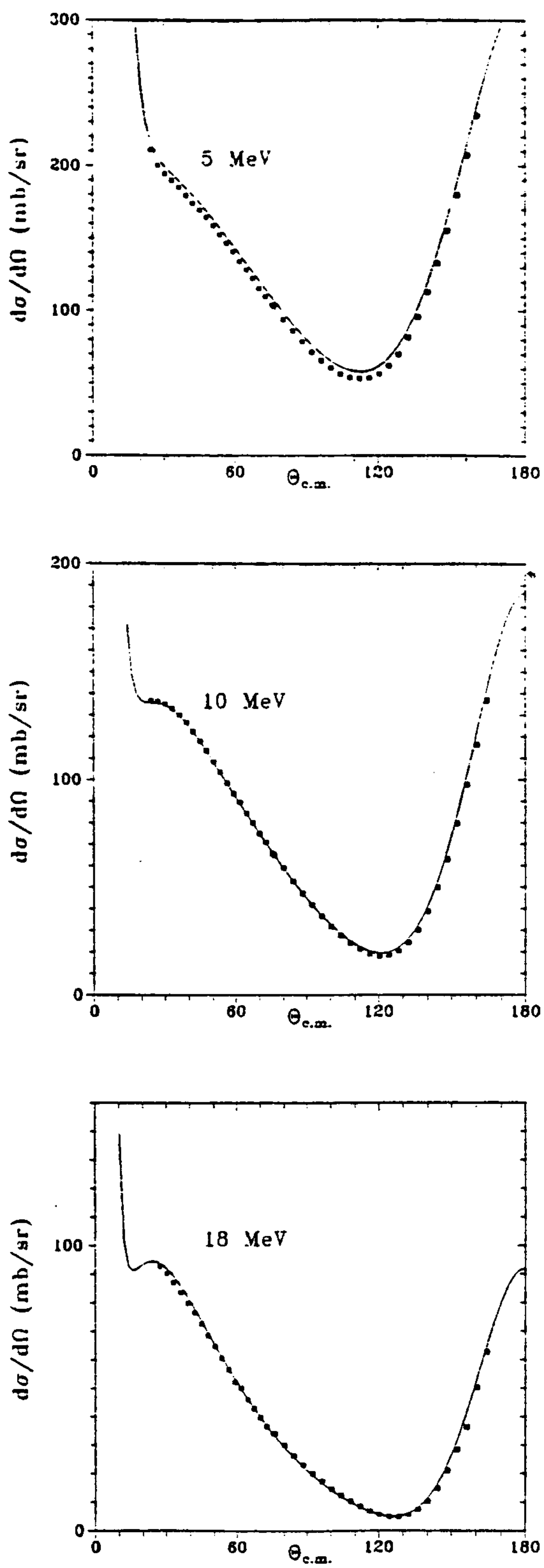

Figure 1: Differential cross sections vs. c.m. scattering angle. Experiment (black squares): Ref. [8] Solid lines present calculations.

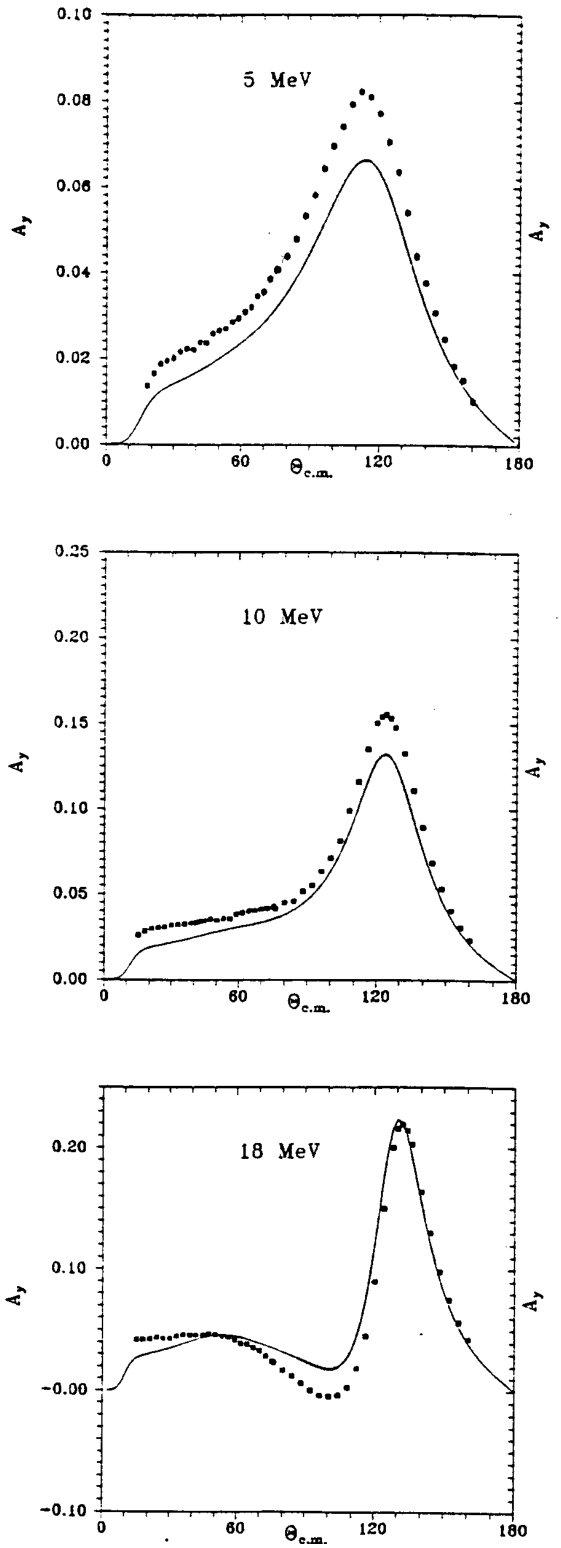

Figure 2: Proton analyzing power. Notation as in Fig. 1. *pd* data from Ref. [8]

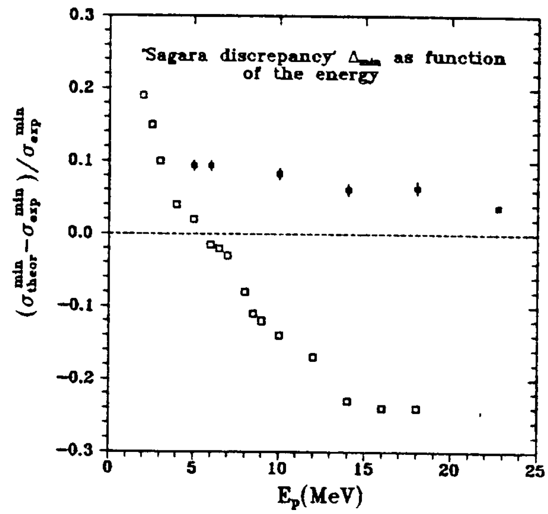

Figure 3: "Sagara discrepancy" as function of the proton laboratory energy. Open squares: Ref. [8], black squares: present calculation.

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