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Deuteron Breakup Differential Cross Sections and Analyzing Powers of $\overrightarrow{d}+p$ Scattering at $E_d = 16$ and 130 MeV

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Abstract Deuteron breakup differential cross sections and analyzing powers for $\overrightarrow{d}+p$ scattering at $E_d = 16$ and 130 MeV are examined using the energy-independent quark-model nucleon-nucleon interaction fss2. The Coulomb effect is incorporated by the sharp cut-off Coulomb force, acting between quarks, without the phase-shift renormalization for the breakup amplitudes. Our results are very similar to those by the meson-exchange potentials, including disagreement for some specific kinematical configurations. The accurate and systematic KVI data at $E_d = 130$ MeV are reasonably reproduced by taking the Coulomb cut-off radius $\rho \geq 16$ fm.

Keywords *nd* and *pd* scattering · Quark-model baryon-baryon interaction · AGS equations

1 Introduction and motivation

In spite of the great success of rigorous three-body approaches [1] to the nucleon-deuteron (Nd) scattering, some three-nucleon ($3N$) observables in the incident energies less than 65 MeV per nucleon are not well reproduced even with the recent accurate treatment of the Coulomb force [2]. This is particularly true for deuteron breakup processes, probably because the breakup amplitude covers a wide momentum region of the three-body phase space. It is therefore worthwhile to reexamine the NN interaction itself if the present-day realistic force is the most appropriate one to start with. In previous studies [3,4], we have applied the quark-model (QM) baryon-baryon interaction

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fss2 [5] to the neutron-deuteron (nd) elastic scattering. This interaction model fss2 describes available NN data in a comparable accuracy with the modern meson-exchange potentials. By eliminating the inherent energy dependence of the resonating-group kernel, fss2 was found to yield a nearly correct triton binding energy [6], S-wave nd scattering lengths and low-energy eigenphase shifts without introducing the $3N$ force [7]. The so-called A_y puzzle at $E_N \leq 25$ MeV is somewhat improved in this model [4].

In this contribution, we examine $3N$ breakup differential cross sections for various decaying kinematics in $E_N \leq 65$ MeV [8]. In particular, the deuteron breakup differential cross sections and analyzing powers of the $\overrightarrow{d} + p$ scattering at $E_d = 16$ MeV [9] and 130 MeV [10–12] are examined in detail, since ample experimental data are available in the latter case. Our main motivation is to find if the quite different off-shell properties, originating from the strong nonlocality of the QM baryon-baryon interaction, affect the $3N$ breakup observables. For this purpose, it is essential to estimate the Coulomb effect of the emerging two protons properly, to compare our results with the experimental data. We find that the half-off shell t-matrix at the final stage of the breakup process needs to be treated carefully, since it is very singular for the small relative momentum between two protons, especially when the Coulomb cut-off radius ρ is taken to be large. We avoid this difficulty by taking a large number of discretization points for the relative momentum between two protons. The two-nucleon partial waves up to $I_{max} = 4$ are included in the present calculation.

2 Results and discussion

Figure 1 shows the breakup differential cross sections for the reaction $H(\overrightarrow{d}, 2p)n$ at $E_d = 16$ MeV, compared with the experimental data [9]. The Coulomb effect from the dashed curves (no Coulomb) to the dotted, solid, and bold curves (with the cut-off Coulomb radius, $\rho = 8$, 16, and 20 fm, respectively) improves the agreement with the experimental data in collinear (COLL1, COLL2) and the non-standard (NS1) configurations, although sometimes overshoots in the $\rho = 20$ fm case. The deuteron analyzing powers are also examined and found to be well reproduced. (Not shown.)

Figure 2 shows the systematic change of the deuteron breakup differential cross sections at $E_d = 130$ MeV in the pp final-state interaction region with $\theta_1 = \theta_2 = 13°$

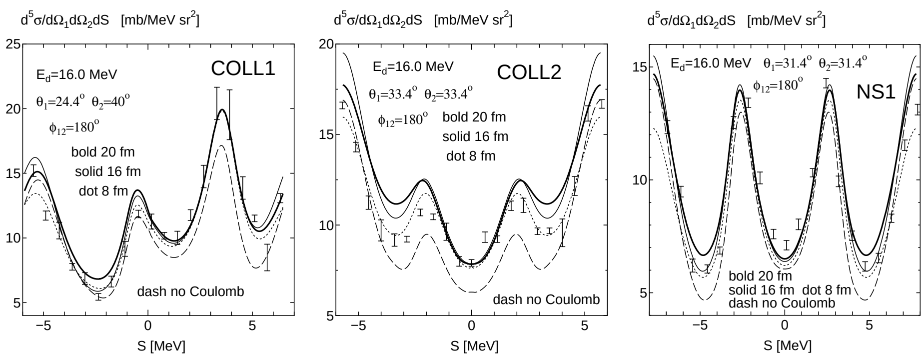

Fig. 1 Breakup differential cross sections for the reaction $H(\overrightarrow{d}, 2p)n$, with the incident deuteron energy $E_d = 16$ MeV. The experimental data are taken from [9].

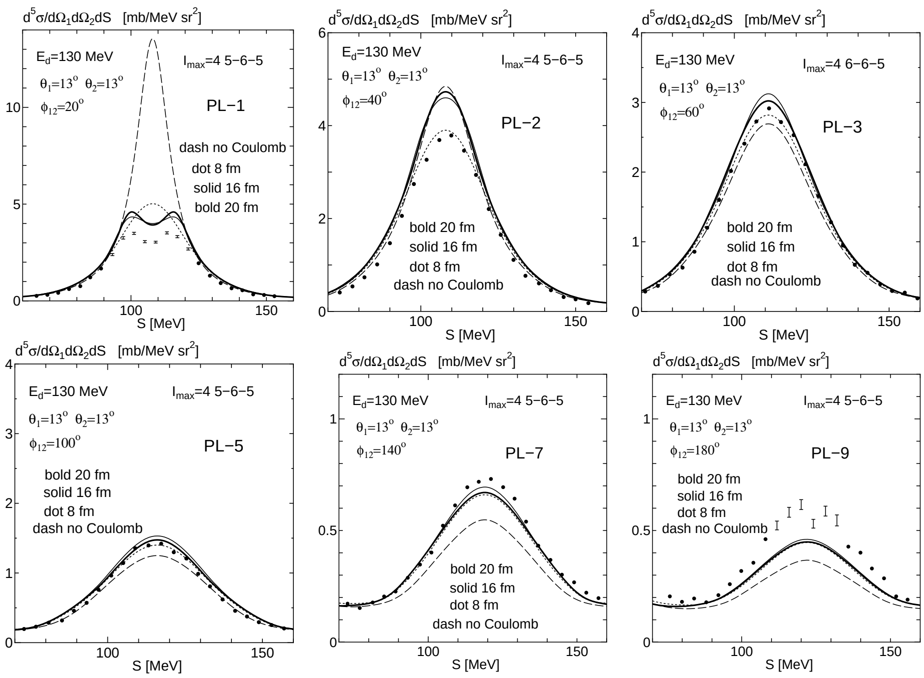

Fig. 2 Breakup differential cross sections for the reaction $H(\overrightarrow{d}, 2p)n$ at the incident deuteron energy $E_d = 130$ MeV. The geometrical configurations are $\theta_1 = \theta_2 = 13°$ and $\phi_{12} = 20°$ - $180°$. The experimental data are taken from [11].

and $\phi_{12} = \phi_1 - \phi_2 = 20°$ - $180°$. When $\phi_{12} = 20°$, the choice $\rho = 8$ fm (dotted curve) is not good enough to reproduce the oscillatory structure, although a large peak in the no-Coulomb case (dashed curve) is strongly suppressed. The characteristic behavior of oscillation is only reproduced if ρ is taken to be sufficiently large with $\rho \geq 16$ fm. The analyzing power in the breakup reaction is even more sensitive to the treatment of the Coulomb force. This is seen in Fig. 3, where deuteron breakup differential cross sections and the analyzing powers are given in some kinematical configurations. In these examples, the results with $\rho = 8$, 16 and 20 fm are rather similar to each other, but for other kinematical configurations with $\theta_1 \sim \theta_2$ and $\phi_{12} = 0°$ unpleasant oscillation appears for $\rho \geq 20$ fm. A larger ρ-value requires more partial waves and makes the solutions of AGS equations more singular. In spite of these limitations for the choice of large ρ, the results of $\rho = 8$ fm are rather stable and show that the Coulomb effect is not so large for $E_N = 65$ MeV except for the *pp* final-state interaction.

3 Summary

We have found that the cutoff Coulomb procedure is in general very successful with rather week cutoff dependence unless the Coulomb effect is large as in the *pp* final-state interaction. The QM baryon-baryon interaction fss2 predicts the *nd* and *pd* scattering observables similar to those given in Refs. [1,2] etc. using the standard meson-exchange potentials. The off-shell effect of fss2, originating from the strong nonlocality, does

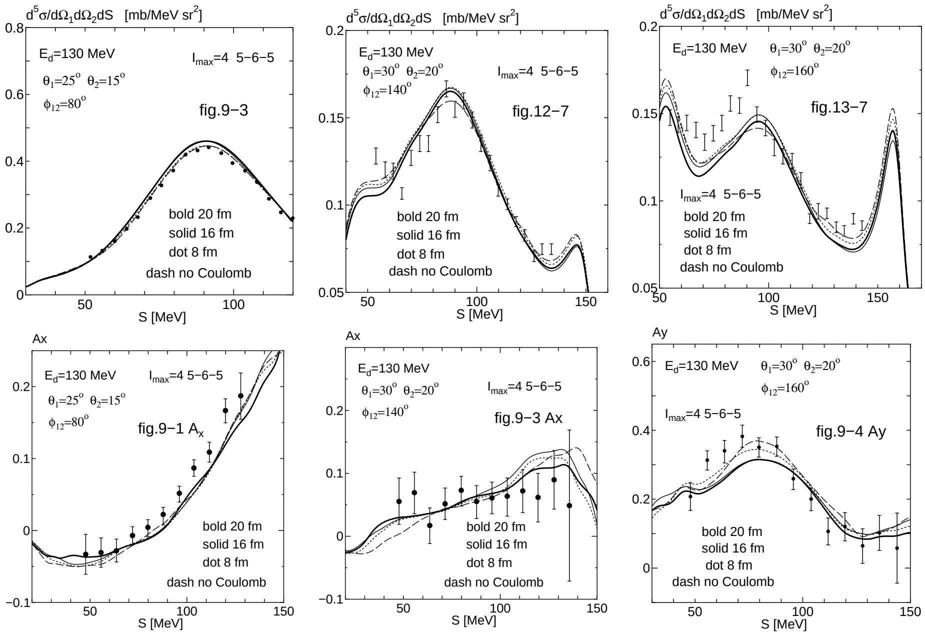

Fig. 3 Breakup differential cross sections and analyzing powers for the reaction $\mathrm{H}(\overrightarrow{d},2p)n$ at the incident deuteron energy $E_d = 130$ MeV. The experimental data are taken from [12].

not improve much the existing discrepancies between the theoretical predictions and experimental data.

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