Quasifree Proton-Deuteron Scattering Corrections Near 210 MeV

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The results of the impulse approximation formalism of Cromer are applied to proton-deuteron inelastic scattering near 210 MeV to obtain corrections relating measured quasifree P_{pp}, P_{np}, and D_{np} data to the respective free parameters.

QUASIFREE proton-deuteron scattering is an inelastic process in which the kinematics of the incident particle and one of the target nucleons approximate those of a free two-nucleon scattering event. The simplest interpretation of these measurements, the spectator model approximation (SMA), assumes that the incident particle interacts with only one target particle, whose initial momentum is given by the deuteron wave function. The other target particle (the spectator) plays no role other than that of conserving momentum. In SMA, the polarization and triple scattering parameters are thus equal to the free nucleon-nucleon parameters.

In a previous publication,[1] we have given a more detailed interpretation of quasifree scattering than the SMA. We used the impulse approximation, including final-state interactions between the two target nucleons for the s state, but neglecting them for higher angular momentum states. Other types of multiple scattering were neglected. The formalism developed was applied to the quasifree p-p and p-n measurements near 140 MeV.

In this article we apply the formalism to the quasifree p-p and p-n measurements near 210 MeV. Except as noted, our procedures are identical to the earlier calculations,[1] to which the reader is referred for all details.

Our treatment of quasifree scattering should be best when the incident particle is scattered into small angles ($<\sim 30°$ lab). Then the relative energy of the two target nucleons is small, and the dominant final-state interaction is an s-state interaction between these particles. For quasifree scattering near 45° lab, our treatment is questionable for several reasons:

(1) The impulse approximation is less valid at the high-momentum transfers which are present at these large scattering angles. In addition, the scattering may be further off the two-nucleon energy shell.

(2) Final-state interactions in p states and higher may be important at the relative energies present for these large angles.

(3) For quasifree p-p scattering near 45° lab, final-state interactions between either proton and the neutron are equally important; our earlier calculation[1] included only the final-state interaction between the neutron and one of the protons, and hence is not fully antisymmetrized. A similar situation exists for quasifree p-n scattering, near 45° lab, in that the final-state interaction between the two protons (neglected in our treatment) is as important as that between neutron and proton. (These shortcomings were not adequately stressed in our previous publication.[1])

The third-mentioned problem is easily solved in principle. In practice, our computer program is not readily adapted to dealing with it for quasifree p-n scattering, but is for quasifree p-p scattering. By summing cross sections in which the scattered and recoil protons exchange roles, and subtracting the spectator model cross section from this sum, a properly antisymmetrized cross section is obtained, which includes final-state interactions between each proton and the neutron. Interference between the two final-state interactions is neglected, and a few small terms, interpretable as due to high-energy spectator particles, are ignored. In a subsequent publication we will treat this problem more fully.

Figure 1 shows corrections to p-p polarization, $\Delta P_{pp}=P_{pp}(\text{free})-P_{pp}(\text{quasifree})$, versus the laboratory angle θ_p of one of the protons. The points are from an experiment of Tinlot and Warner.[2] The curve shows our calculation and includes the changes described in the preceding paragraph. This modification is unimportant for angles smaller than 70° c.m. Note that theory and experiment agree.

Table I lists the polarization in quasifree p-n scattering, P_{pn}(quasifree), as measured by Tinlot and Warner[2]; the calculated correction to it, ΔP; and the inferred free n-p scattering polarization parameter, P_{np}. (The quasifree measurements extend to 120° c.m.; however, we do not feel justified in quoting corrections at angles larger than 90° c.m., for the 3 reasons discussed above.)

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[1] A. H. Cromer and E. H. Thorndike, Phys. Rev. **131**, 1680 (1963).

[2] J. H. Tinlot and R. E. Warner, Phys. Rev. **124**, 890 (1961).

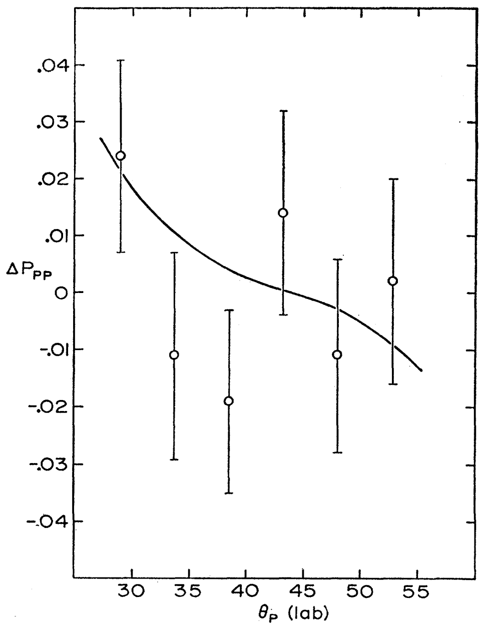

FIG. 1. $\Delta P_{pp}=P_{pp}(\text{free})-P_{pp}(\text{quasifree})$ as a function of the laboratory angle θ_p of one of the protons. The experimental points are from Tinlot and Warner, Ref. 2. The curve represents the calculated values of ΔP_{pp}, after summing over the final-state interaction between each proton and the neutron (see text). The calculated values of ΔP_{pp} are uncertain to ± 0.01, chiefly as a result of variations in the set of scattering amplitudes used.

Table II lists similar information for the *n-p* triple scattering parameter *D*. Experimental values are due to Warner and Tinlot.[3] Unlike the quasifree *p-p* calculations, the quasifree *p-n* calculations have *not* been modified to deal with the third-mentioned problem above. It is felt that the *systematic* error, described below, more than allows for this omission.

TABLE I. Polarization in quasifree *p–n* scattering (Ref. 2), the correction to it, and the inferred free *n–p* scattering polarization parameter. There is a systematic error of $[(0.04)^2+(\frac{1}{4}\Delta P)^2]^{1/2}$ in the inferred free parameter (see text) in addition to the listed error.

θ_p(lab)	P_{pn}(quasifree)	ΔP	P_{pn}(free)	θ_p (c.m.)
19.2°	0.468±0.029	0.033±0.019	0.501±0.035	40°
24.1°	0.460±0.031	0.006±0.021	0.466±0.038	50°
28.8°	0.372±0.041	−0.010±0.016	0.362±0.044	60°
33.6°	0.258±0.033	−0.018±0.013	0.240±0.035	70°
38.4°	0.032±0.036	−0.020±0.013	0.012±0.038	80°
43.2°	−0.069±0.032	−0.018±0.011	−0.087±0.034	90°

TABLE II. Depolarization in quasifree *p–n* scattering (Ref. 3), the correction to it, and the inferred free *n–p* scattering depolarization parameter. There is a systematic error of $[(0.04)^2+(\frac{1}{4}\Delta D)^2]^{1/2}$ in the inferred free parameter (see text) in addition to the listed error.

θ_p(lab)	D_{np}(quasifree)	ΔD	D_{np}(free)	θ_p(c.m.)
19.2°	0.71±0.07	0.08±0.05	0.79±0.09	40°
24.1°	0.85±0.08	0.05±0.03	0.90±0.09	50°
28.8°	0.79±0.08	0.03±0.03	0.82±0.08	60°
33.6°	0.99±0.14	0.02±0.02	1.01±0.14	70°
38.4°	1.05±0.45	0.01±0.01	1.06±0.45	80°

The errors listed on the corrections are due to uncertainties in the scattering amplitude used, and errors from averaging over the range in angles and energy present in the experimental situation. (A major contribution to the errors comes from a lack of knowledge of the energy dependence of the neutron detector efficiency. Such information is an important part of any quasifree *p-n* measurement.) Not listed is the uncertainty due to the limited validity of the theory. At 140 MeV,[1] we inferred, from the agreement with quasifree *p-p* experiments, an error of $[(0.04)^2+(\frac{1}{4}\Delta P)^2]^{1/2}$ to ΔP, with a similar expression holding for ΔD. We believe that this is a reasonable estimate at 210 MeV, too. The comparison of our predicted corrections with experimentally determined values for ΔP_{pp} (see Fig. 1) gives no indication that this estimate is low. Note that this is a *systematic* error, which should vary smoothly with scattering angle.

At small angles our corrections bring the measured values for[4] D_{np} and[5] P_{np} into better agreement with the Yale phase parameter solutions[6] YLAN 3*M* and YLAN 3, respectively. However, at larger angles the corrections move the points away from these solutions.

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[3] R. E. Warner and J. H. Tinlot, Phys. Rev. **125**, 1028 (1962).

[4] See Fig. 3 of Ref. 3.
[5] See Fig. 6 of Ref. 2.
[6] M. H. Hull, Jr., K. E. Lassila, H. M. Ruppel, F. A. McDonald, and G. Breit, Phys. Rev. **122**, 1606 (1961).