Screening correction for hadron-deuteron absorption cross sections near 200 GeV/c

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We have determined the screening-correction factor G_a for proton-deuteron and positive-pion–deuteron absorption cross sections near 200 GeV/c. The determination uses measured cross sections on nucleon and deuteron targets, with an assumption about the one- and two-prong absorption cross sections on deuterons. The values found for G_a are larger than the corresponding total-cross-section screening-correction factors, but are in reasonable agreement with a simple geometrical prediction.

I. INTRODUCTION

We have used measured cross sections to determine the screening correction $\delta\sigma_a$, and thence the correction factor G_a, for proton-deuteron and pion-deuteron absorption cross sections near 200-GeV/c incident momentum. Here the absorption cross section corresponds to all processes in which the incident hadron disappears during the collision or reappears with one or more produced particles. The quantities $\delta\sigma_a$ and G_a are defined, for an incident hadron h, as follows:

$$\delta\sigma_a = \sigma_a(hd) - \sigma_a(hp) - \sigma_a(hn) , \quad (1)$$

$$G_a = \frac{-\delta\sigma_a}{\sigma_a(hp) + \sigma_a(hn)} = 1 - \frac{\sigma_a(hd)}{\sigma_a(hp) + \sigma_a(hn)} . \quad (2)$$

[Note that the denominator in Eq. (2) contains the sum of the nucleon cross sections rather than the deuteron cross section; the choice is arbitrary.]

We know of no previous accurate determination of $\delta\sigma_a$ or G_a. An experimental problem that hinders any such determination is the difficulty in separating the pseudoelastic reaction $hd \to hpn$ from topologically similar absorption reactions such as $hd \to hpn\pi^0$. That is, the one- and two-prong contribution to the absorption cross section is difficult to measure (prong counts, or final-state charge multiplicities, assume a charged incident hadron).

Over 20 years ago, Glauber[1] predicted from simple geometrical considerations

$$\delta\sigma_a = -\sigma_a(hp)\sigma_a(hn)\,\langle r^{-2}\rangle /2\pi , \quad (3)$$

where $\langle r^{-2}\rangle$ is the mean inverse square deuteron radius. The resulting prediction for G_a is in general different from the prediction for the total-cross-section correction factor, G_T, which follows from the simple formula[1,2] (which neglects isospin complications,[3] and assumes purely imaginary forward scattering amplitudes with a momentum-transfer dependence much smaller than that for the deuteron form factor)

$$\delta\sigma_T = -\sigma_T(hp)\sigma_T(hn)\langle r^{-2}\rangle/4\pi . \quad (4)$$

We note that the ratio between $\delta\sigma_a$ and $\delta\sigma_T$ given by Eqs. (3) and (4) is also obtained, to a very good approximation (within 5% at 200 GeV/c) from the detailed formulas given by Franco and Glauber.[2]

It is clearly of interest to compare the predictions of Eq. (3) with experimental results. In addition, a measurement of G_a is important to experiments that attempt to extract free-neutron inelastic cross sections from measurements on deuterons.[4] Such experiments often assume that $G_a \simeq G_T$. Finally, G_a may be relevant to rescattering studies[5]; for example, in deuterium the parameter $\bar{\nu} = A\sigma_a(hp)/\sigma_a(hA)$, which is used extensively in studies of hadron-nucleus interactions,[6] is related to G_a by the equation

$$1 - G_a = 1/\bar{\nu} . \quad (5)$$

II. DETERMINATION OF G_A

Recently, bubble-chamber experiments[7,8] have reported accurate measurements of $\sigma_a(hd)$, for incident protons and negative pions with momenta near 200 GeV/c, for three and more prongs. At this high energy, the one- and two-prong absorption cross sections are relatively smaller than at lower energies, and reasonable estimates of their magnitudes can be made. Then, with the help of measured hadron-nucleon cross sections, we can determine the quantity G_a.

We estimate the one- and two-prong absorption cross sections with the formulas

$$\sigma_a(hd, N=1,2) = (1 - G_a)[\sigma_a(hn, N=1) + \sigma_a(hp, N=2) + \Delta](1 - \alpha R) , \quad (6)$$

$$\Delta = \int \frac{d\sigma}{dt}\,(hp \to pX, N=2)2S(t)dt , \quad (7)$$

$$\alpha = 0.5 \pm 0.5 \, . \tag{8}$$

Here R equals the fraction of hd events with $N \geq 3$ that rescatter, N equals the prong count, and $S(t)$ is the deuteron form factor. Equation (6) follows from a spectator model of the hadron-deuteron interaction, with a screening correction and with allowance for multiplicity-increasing rescattering. We assume that the screening-correction factor is just G_a, and we assume that the probability of a multiplicity-increasing rescatter following a one- or two-prong hadron-nucleon inelastic interaction is between zero and R. The term Δ arises from the symmetry requirements of the two-nucleon wave function.[9] The expression for Δ in Eq. (7) assumes that nucleon spin-flip and charge-flip contributions to $\sigma_a(hp, N=2)$ are negligible at values of the four-momentum transfer t where $S(t)$ is non-negligible.

We believe that Eq. (6), with the rather generous errors on the multiplicity-increasing rescatter probability, should be valid. Similar formulas are almost always implied, at least at beam momenta above ~1 GeV/c, when free-neutron cross sections are extracted from deuterium data. At Fermilab energies, studies of multiplicity distributions[5,7,8,10] indicate at most small differences between the multiplicity distributions of hadron-deuteron interactions that have a spectator nucleon and of free hadron-nucleon interactions, in agreement with the primary assumption in Eq. (6). Also, the observation[5,7,8,10] that rescattering produces rather small increases in mean multiplicity over that for hadron-nucleon interactions indicates a value for α of ~0.5 rather than ~1.0.

Combining Eq. (2) and Eq. (6) yields

$$1 - G_a = \frac{\sigma_a(hd, N \geq 3)}{\sigma_a(hn) + \sigma_a(hp) - [\sigma_a(hn, N=1) + \sigma_a(hp, N=2) + \Delta](1 - \alpha R)} \, . \tag{9}$$

This is the equation we actually use to determine G_a. We have neglected $\sigma_a(\pi^- d, N=0)$, which we expect to be ~0.01 mb since[11] at 205 GeV/c, $\sigma_a(\pi^- p, N=0) \approx 0.01$ mb.

There are no direct measurements available of $\sigma_a(hn, N=1)$, so we estimate values as follows:

$$\sigma_a(\pi^- n, N=1) = (0.6 \pm 0.1)\sigma_a(\pi^+ p, N=2) \, , \tag{10}$$

$$\sigma_a(pn, N=1) = (0.6 \pm 0.1)\sigma_a(pp, N=2) \, . \tag{11}$$

Relations of this form follow[10] from charge symmetry and, in the incident proton case, vertex independence considerations. The numerical factor in each case represents the probability that, in a two-prong inelastic interaction, a struck proton remain a proton or yield a hyperon-positive kaon pair. Values of 0.6 ± 0.1 are suggested by 100-GeV/c data,[10] and are expected to vary little with energy. We take $\sigma_a(pp, N=2)/\sigma_a(pp)$ from Ref. 12, and $\sigma_a(\pi^+ p, N=2)/\sigma_a(\pi^+ p)$ from Ref. 11, assuming[13] that $\pi^+ p$ and $\pi^- p$ multiplicity distributions are the same near 200 GeV/c.

We take $\sigma_a(hp) = \sigma_T(hp) - \sigma_{el}(hp)$, and use measured total cross sections[14,15] at 200 GeV/c. We assume that the elastic-to-total-cross-section ratios[16] at 200 GeV/c are the same as those at 175 GeV/c (they exhibit little change between 100 and 175 GeV/c), and are the same for pn as for

TABLE I. Quantities involved in the determination of G_a. Values of Δ, G_a, and $\sigma_a(hd, N=1,2)$ are calculated from Eqs. (7), (9), and (6), respectively (see text).

Quantity	205 GeV/c $\pi^- d$	200 GeV/c pd
$\sigma_a(hd, N \geq 3)$ (mb)	35.43 ± 0.33, Ref. 8	55.05 ± 0.78, Ref. 7
R	0.14 ± 0.01, Ref. 8	0.174 ± 0.018, Ref. 7
$\sigma_T(hp)$ (mb)	24.33 ± 0.10, Ref. 14	38.97 ± 0.16, Ref. 14
$\sigma_T(hn)$ (mb)	23.84 ± 0.10, Ref. 14	39.67 ± 0.24, Ref. 15
$\sigma_{el}(hp)/\sigma_T(hp)$	0.140 ± 0.005, Ref. 16	0.182 ± 0.007, Ref. 16
$\sigma_{el}(hn)/\sigma_T(hn)$	0.143 ± 0.004, Ref. 16	0.182 ± 0.007 [a]
$\sigma_a(hp, N=2)/\sigma_a(hp)$	0.080 ± 0.004, Ref. 11	0.089 ± 0.008, Ref. 12
$\sigma_a(hn, N=1)/\sigma_a(hn)$	0.048 ± 0.008 [b]	0.053 ± 0.010 [c]
Δ (mb)	0.26 ± 0.04	0.36 ± 0.07
G_a	0.083 ± 0.011	0.080 ± 0.018
$\sigma_a(hd, N=1,2)$ (mb)	2.49 ± 0.25	4.13 ± 0.54
$P_{a,2}(hd)$ [d]	0.066 ± 0.006	0.070 ± 0.008

[a] Assumed equal to pp value.
[b] Via Eq. (10).
[c] Via Eq. (11).
[d] $\sigma_a(hd, N=1,2)/\sigma_a(hd)$.

pp. Charge symmetry allows the use of π^+p total and elastic cross sections for π^-n cross sections. We evaluate the quantity Δ using exponential fits to the $d\sigma/dt$ data[17,18] and using a sum of Gaussians[19] for $S(t)$.

Finally, the values we insert into Eq. (9), and the resulting values of G_a, are given in Table I. The major contribution to the error in G_a comes from the error in $\sigma_a(hd, N\geq 3)$, for both π^-d and pd. Also given in Table I are the values of $\sigma_a(hd, N=1,2)$ and of $P_{a,2}(hd)=\sigma_a(hd,N=1,2)/\sigma_a(hd)$ obtained from Eq. (6). To indicate the sensitivity of G_a to $\sigma_a(hd,N=1,2)$, we note that a 10% change in the latter would alter G_a by 0.006, for both π^-d and pd.

III. DISCUSSION

In Table II our experimental values of G_a are compared to values predicted by Eq. (3) and to values of G_T [as discussed above, the experimental G_a values do have a theoretical component, via Eq. (6)]. The G_T values are obtained from measured $\pi^\pm p$, $\pi^\pm d$, pn, pp, and pd total cross sections.[14,15] The predictions for G_a use the values of $\langle r^{-2}\rangle$, given in Table II, which follow from the G_T values and Eq. (4). Since the derivation of Eq. (4) involves some assumptions (as mentioned above) and also neglects an inelastic-screening term which may be non-negligible,[15] our $\langle r^{-2}\rangle$ values should be considered "effective" values. The errors in the predicted G_a values are almost wholly due to the errors in $\langle r^{-2}\rangle$.

TABLE II. Comparison of experimental G_a values with predicted values and with G_T values.

Quantity	205 GeV/c π^-d	200 GeV/c pd
G_a (expt.)	0.083 ± 0.011	0.080 ± 0.018
G_T (expt.)	0.038 ± 0.002	0.059 ± 0.006
$\langle r^{-2}\rangle$ [a] (mb^{-1})	0.040 ± 0.002	0.037 ± 0.004
G_a [b]	0.066 ± 0.003	0.095 ± 0.010

[a] Via Eq. (4).
[b] Via Eq. (3).

Table II shows that the experimental G_a values are larger than the G_T values, by several standard deviations in the π^-d case. Also, the experimental and predicted values of G_a agree in the pd case, and differ by 1.5 standard deviations in the π^-d case, where the errors are smaller.

We conclude that Eq. (3) provides a bettter estimate of G_a than does the assumption that $G_a=G_T$. The question of the accuracy of Eq. (3), or of what value of $\langle r^{-2}\rangle$ to use in Eq. (3), must await more accurate measurements of $\sigma_a(hd)$. However, the use of Eq. (3), with $\langle r^{-2}\rangle$ taken from Eq. (4), does not lead to any strong disagreement with the present data.

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