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THE SCREENING CORRECTION FOR HADRON-DEUTERON ABSORPTION CROSS SECTIONS NEAR 200 GeV/c

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ABSTRACT

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:

$$\delta\sigma_a = \sigma_a(hd) - \sigma_a(hp) - \sigma_a(hn) \tag{1}$$

$$G_a = \frac{-\delta\sigma_a}{\sigma_a(hp) + \sigma_a(hn)}$$

$$= 1 - \frac{\sigma_a(hd)}{\sigma_a(hp) + \sigma_a(hn)} \tag{2}$$

(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 pseudo-elastic reaction hd $\rightarrow$ hpn from topologically similar abosrption reactions such as hd $\rightarrow$ hpnπ^o. 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 twenty years ago, Glauber[1] predicted, from simple geometrical considerations:

$$\delta\sigma_a = -\sigma_a(hp)\sigma_a(hn) < r^{-2} >/2\pi \tag{3}$$

where $< r^{-2}>$ 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):

$$\delta\sigma_T = -\sigma_T(hp)\sigma_T(hn)< r^{-2} >/4\pi \tag{4}$$

We note that the ratio between $\delta\sigma_a$ and $\delta\sigma_T$ given by Equations (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:

$$1 - G_a = 1/\bar{\nu} \tag{5}$$

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:

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

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

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

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:

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

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 $\sigma_a(\pi^- p, N=0) \simeq 0.01$ 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 GeV/c and 175 GeV/c), and are the same for pn as for pp. Charge symmetry allows the use of $\pi^+ p$ total and elastic cross sections for $\pi^- n$ 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 $\pi^- d$ 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 $\pi^- d$ 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 $< r^{-2} >$, 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 $< r^{-2} >$ values should be considered "effective" values. The errors in the predicted G_a values are almost wholly due to the errors in $< r^{-2} >$.

Table II shows that the experimental G_a values are larger than the G_T values, by several standard deviations in the $\pi^- d$

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 better 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 $< r^{-2} >$ to use in Eq. (3), must await more accurate measurements of σ_a(hd). However, the use of Eq. (3), with $< r^{-2} >$ taken from Eq. (4), does not lead any strong disagreement with the present data.

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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 Equations 7, 9, and 6 respectively (see text).

Quantity	205 GeV/c π^-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]$\sigma_a(hd,N=1,2)/\sigma_a(hd)$

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)