The analysing powers in proton-deuteron elastic scattering

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Abstract

It is shown that the ratio of the deuteron and proton analysing powers in proton-deuteron elastic scattering at small angles is sensitive to subtle effects in a theoretical description. These include the transverse spin-spin term in the elementary nucleon-nucleon amplitudes and double-scattering corrections. On the other hand there is far less sensitivity to the spin-orbit amplitude and to binding or other kinematic effects associated with the use of the deuteron, as either target or projectile. The available data are in agreement with the results of a refined Glauber theory model.

\textit{Keywords:} Deuteron-proton elastic scattering, Polarisation effects

In the analysis of their data on proton-deuteron elastic scattering at 796 MeV, the authors of Ref. \textsuperscript{[1]} pointed out that, at small c.m. momentum transfer $q$ between the initial and final proton momenta, the proton analysing power $A_y^p$ is dominantly determined by an interference of charge-average spin-independent nucleon-nucleon amplitudes with the corresponding spin-orbit term. This is in contrast to the differential cross section, which is significantly reduced by the interaction of the proton with both constituents of the deuteron \cite{1}. If this approach provides a good approximation for $A_y^p$, one should check whether it leads to a reasonable description of the deuteron vector analysing power $A_y^d$. It is the purpose of this note to compare the values of $A_y^d$ and $A_y^p$ in $pd$ elastic scattering by evaluating the ratio

$$R = A_y^d/A_y^p$$  \hspace{1cm} (1)

at various beam energies and momentum transfers in order to investigate deviations from the simple model proposed in \cite{1} which, as discussed in the Appendix, would suggest that $R = 2/3$.

Any investigation of $R$ is hampered by a lack of data on either $A_y^p$ or $A_y^d$ at similar energies per nucleon. However at 796 MeV, in addition to the $A_y^p$ data given in \cite{1}, there are also measurements from COSY-ANKE \cite{2}. These are complemented by measurements of the deuteron analysing power in $dp$ elastic scattering in the 800 MeV per nucleon region \cite{3} \cite{4} \cite{5}. The resulting values of $R$ are reported in Fig. \textbf{2} as function of the magnitude of the momentum transfer $q$. The error bars are statistical and do not take into account the systematic uncertainties associated with the beam polarisations in the various experiments.

By using a polarised deuterium target, together with a polarised proton beam, it was possible at IUCF to measure both the proton and deuteron analysing powers in $pd$ elastic scattering in the same experiment \cite{6}. The results obtained at 135 and 200 MeV are also shown in Fig. \textbf{2} though, for clarity of presentation, these have been displaced downwards by 0.4 and 0.2, respectively.

The only other published data where the ratio can be evaluated were taken at 250 MeV per nucleon \cite{7} \cite{8} but, due to the lack of small angle deuteron data, only two points could be used and these yielded $R = 0.65 \pm 0.03$ and $R = 0.66 \pm 0.01$ at $q = 1.45$ fm$^{-1}$ and 1.59 fm$^{-1}$, respectively. These values are clearly compatible with $R = 2/3$, especially if one adds to the statistical errors the 3% systematic uncertainty in the beam polarisations.

The data shown in Fig. \textbf{2} are more or less consistent with the simple-minded expectation of $R = 2/3$ at low $q$ but the values of $R$ appear not to be constant. It is therefore of interest to see what $q$ dependence is to be expected in more realistic theoretical models. The most transparent approach, especially at the higher energies, is a generalisation of the Glauber eikonal model \cite{9}. Here all the spin-dependence of the nucleon-nucleon amplitudes is retained \cite{10}, though the cancellation of the higher order terms \cite{11} can no longer be guaranteed because of the non-commutativity of some of the amplitudes. Though this approach has been used to describe the differential cross section \cite{12}, it can also be used in the study of polarisation observables \cite{10}. For example, the individual analysing powers have already been studied in this model at 135 MeV and 200 MeV \cite{12}.

In the Glauber model, the $pd \rightarrow pd$ elastic scattering amplitude contains terms corresponding to single and double scattering of the proton on, respectively, one or two nu-
The 2/3 factor is discussed further in the Appendix.
spin amplitude, all in the limit of \( q \to 0 \). The small relativistic correction to the spin-orbit amplitude \([16, 10]\) vanishes as \( q \to 0 \) and has here been neglected.

It can be seen from Eq. (2) that the ratio is independent of the size of the spin-orbit amplitude and so binding corrections to the spin-orbit amplitude are of little importance. As a consequence, a precise measurement of \( R \) could provide some information on the \( NN \) transverse spin-spin amplitude in the forward direction that is independent of the extraction of the imaginary part of amplitude via the spin dependence of total cross sections and the evaluation of the corresponding real part from forward dispersion relations \([17]\).

The analysing powers of both the proton and deuteron in the \( pd \to pd \) scattering have similar shapes as functions of \( q \) \([4]\). However, due in part to the multiple scattering, the position of the zeroes in \( A^p_y \) and \( A^d_y \) are displaced slightly and so in this region their ratio can fluctuate strongly. For smaller values of \( q \), which are those shown in Fig. 1 the ratio \( R \) varies little from its standard value of \( 2/3 \). Nevertheless, its \( q \) dependence is quite similar to that expected on the basis of the refined Glauber model, where the spin dependence of the double scattering is taken seriously \([10]\).

The simplest model that can generate both proton and deuteron non-zero analysing powers in \( dp \) elastic scattering has a transition operator of the form

\[
\hat{M} = a + i b \hat{S}_y + c \hat{S}_y^3.
\]

(3)

Here \( \hat{S}_y \) and \( \hat{S}_y^3 \) are operators acting, respectively, on the spins of the proton and deuteron. The proton analysing power results from an interference between the amplitudes \( a \) and \( b \) whereas that of the deuteron is due to an interference between \( a \) and \( c \). Straightforward calculations yield

\[
A^p_y = 2 I m \{ a b^* \} |a|^2 + |b|^2 + \frac{2}{3} |c|^2],
\]

\[
A^d_y = \frac{1}{3} I m \{ a c^* \} |a|^2 + |b|^2 + \frac{2}{3} |c|^2].
\]

(4)

However, in the single scattering approximation at low \( q \), neglecting the small relativistic correction \([16]\), the spin-dependent amplitudes are equal, \( b = c \) \([10]\). It then follows that \( A^p_y = \frac{4}{3} A^d_y \), where the \( 2/3 \) factor actually arises from the fact that for \( A^d_y \) one has to sum over the two spin projections of the proton, whereas for \( A^p_y \) the sum is over the three spin projections of the deuteron. Deviations from \( 2/3 \) at low \( q \) are primarily due to the spin-spin amplitudes and the double scattering, both of which are included in the refined Glauber model \([10]\).

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