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To cite this version:

HAL Id: jpa-00230930
https://hal.archives-ouvertes.fr/jpa-00230930
Submitted on 1 Jan 1990

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SPIN PHYSICS IN THE \(d(e,e'p)\) REACTION

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Abstract—Dependences of the proton polarization in \(d(e,e'p)n\) and \(d(3,elp)n\) reactions on the choice of the electromagnetic(EM) deuteron current and final-state interaction(FSI) effects are investigated. Separation of the longitudinal-transverse structure function(SF) for this observable in the \(d(e,e'p)n\) reaction is discussed. Calculations of the proton polarization in the \(d(e,e'p)n\) reaction have been carried out for the MIT kinematics.

1—INTRODUCTION

In view of the construction of CW electron accelerators, polarization phenomena in EM interactions with atomic nuclei attract a constantly increasing interest. The corresponding polarization observables(e.g., nucleon polarization, target asymmetries) contain much richer information on the reaction mechanism and nuclear structure than that attainable with unpolarized particles. These observables, being dependent on interference terms of various reaction amplitudes, can be very sensitive to the contributions of subnuclear degrees of freedom(e.g., meson exchange currents(MEC)) and effects of the FSI. Here we demonstrate this by calculating the proton polarization in the \(d(e,e'p)n\) reaction. Therefore, the investigation of the polarization versus the proton emission angle at various relative energies of the p-n pair can give an additional information on the p-n interaction. To attain a deeper understanding of the role of meson exchange effects in the simplest nuclear system, we put special emphasis on a certain consistency of the MEC models with the N-\(\bar{N}\) interaction models. To this end, we have used the one-boson exchange models with modified meson-nucleon vertices/1,2/.

2—STUDY OF PROTON POLARIZATION IN \(d(e,e'p)n\) FOR THE MIT EXPERIMENT

The transverse \(P_\perp\), longitudinal \(P_\parallel\) and normal \(P_\|\) components of the proton polarization in the \(d(e,e'p)n\) reaction with longitudinally polarized electrons for coplanar kinematics can be written as

\[
\frac{\partial P_\perp}{\partial(2)} = \frac{\lambda}{Q} \sum_I \left( \frac{\xi}{\sum I} + \frac{\sqrt{\xi + \eta}}{\sum I} \right) R_{n\to r} \right) \theta,
\]

\[
\frac{\partial P_\parallel}{\partial(1)} = \frac{\lambda}{Q} \sum_I \left( \frac{\xi^2}{\sum I} + \frac{\xi + \eta}{\sum I} \right) R_{n\to r} \theta,
\]

where \(\lambda\) is the incident electron helicity, \(\lambda\) is the recoil factor. We have chosen the orthonormal basis: \(\vec{r}_z = \vec{q}/Q\), \(\vec{r}_\perp = \vec{k} \times \vec{k}'/|\vec{k} \times \vec{k}'|\) and \(\vec{r}_\parallel = \vec{r}_\parallel x \vec{r}_z\). Assuming that \(\vec{r}_\parallel\) and \(\vec{r}_z\) form the reaction plane, \(\vec{k}(\vec{k}')\) is the momentum of the incident (scattered electron), \(\vec{q} = \vec{k} - \vec{k}'\). The SF \(\sum_I\) and \(\sum_I\) depend on the bilinear combinations of the reaction amplitudes(see/3/for details).
The results of our calculations for the MIT I(III) kinematics /4/ are shown in Fig.1.

![Graph showing angular dependence of polarization observables for MIT I and II kinematics.](image)

Fig.1- The angular dependence of polarization observables for the MIT I (left) and MIT II(right) kinematics/4/. The curves calculated with $\lambda = 1$ are: dashed-in the plane wave Born approximation, solid (dash-dotted)-taking into account the FSI for the MEC/2/ with the cut-off parameter $\lambda = 4m_\pi$ (without MEC), where $m_\pi$ is the pion mass, $\theta (\theta')$ is the angle between the outgoing proton momentum and $\vec{q}$ in the lab. frame (the centre-of-mass frame).

As seen from the figures, for parallel kinematics ($\theta = 0^\circ$) the FSI and MEC contributions to the proton polarization are small. The same is true near $\theta_{\text{lim}} = 90^\circ$ as the recoil neutron has the momentum $\vec{k}_n = \vec{q}$. The FSI influence on the components $P_x$ and $P_z$ becomes significant at intermediate $\theta$ values.

The component $P_y$ is equal to zero without the FSI. As to the MEC effects, their contributions to the polarisation under these kinematic conditions are comparatively small. So, the proton polarization has the values accessible for the planned measurements.

3-SEPARATION OF THE LONGITUDINAL-TRANSVERSE SF FOR THE PROTON POLARIZATION IN THE $d(e,e'p)n$ REACTION

The proton polarization in the $d(e,e'p)n$ reaction with unpolarized initial particles for coplanar kinematics determined by (2).

In parallel kinematics (protons detected along $\vec{q}$), there is only one SF which survives /3/. It depends on the interference between the longitudinal and transverse components of the deuteron EM current. The dependence of $\Sigma I$ on the angle $\theta$ between the momentum $\vec{k}_p$ of the outgoing proton and $\vec{q}$ can be obtained by measuring the azimuthal (left-right) asymmetry of the proton polarization

$$\Sigma I = \frac{\sigma(\phi=0)P_y(\phi=0) + \sigma(\phi=\pi)P_y(\phi=\pi)}{2\sigma_M R^f \sqrt{\frac{k^2}{k^2+\eta}}}$$  

where the azimuthal angle $\phi$ equals $180^\circ (0^\circ)$ if $\vec{k}_p$ lies on the right (left) of $\vec{q}$.

Our calculations for the initial electron energy $E_e = 1$ GeV have shown
that (i) in the left wing of the quasi-free peak (QFP) with the scattered electron energy $E_e = 827$ MeV, $\theta_e = 50^\circ$, $q = 788$ MeV/c, the n-p relative energy in the c.m. frame $E_{\text{np}}^{26} = 13.2$ MeV, the kinetic proton energy in the lab frame $T_p = 131.8$ MeV, the recoil neutron momentum $k_n = 273$ MeV/c and the $d^3\sigma$ cross section $\hat{\sigma} = 0.015$ nb·MeV$^{-1}$·sr$^{-2}$, the proton polarization is $P = -36\%$.

(ii) in the right wing of the QFP with $E_e = 830$ MeV, $\theta_e = 10^\circ$, $q = 233$ MeV/c, $E_{\text{np}}^{26} = 155$ MeV, $T_p = 128$ MeV, $k_n = 275$ MeV/c and $\hat{\sigma} = 1.4$ nb·MeV$^{-1}$·sr$^{-2}$, we get $P = -12\%$.

![Graphs showing angular dependence of $\sum I_x$ in the left (left part) and right (right part) wings of the QFP. The curves have been calculated taking into account the FSI: solid (dotted) for the MEC with $A = 4m$, dash-dotted without the MEC.](image)

Fig. 2- The angular dependence of $\sum I_x$ in the left (left part) and right (right part) wings of the QFP. The curves have been calculated taking into account the FSI: solid (dotted) for the MEC with $A = 4m$, dash-dotted without the MEC.

As seen from the figures 2, the SF is essentially sensitive to the MEC model. This fact can be used to verify our understanding of the mechanisms of deuteron electrodisintegration.

**4-DEPENDENCE OF PROTON POLARIZATION IN $d(e,e'p)n$ AND $d(e,e'p)n$ ON THE NEUTRON ELECTRIC FORM FACTOR (PP).**

The proton polarization $P_x$ in the $d(e,e'p)n$ reaction with unpolarized initial particles for coplanar kinematics has the only component $P_Y$ perpendicular to the scattering plane (cf. sec. 3).

It is induced by the FSI in the n-p system. Our calculations (Korchin, Mel'nik, and Shebeko, to be published) for the energy transfers corresponding to the region between the deuteron electrodisintegration threshold and the quasi-free peak in the $d^2\sigma$ cross sections in the inclusive $d(e,e')p$ reaction have shown an appreciable sensitivity of $P_Y$ to the model of $G_E^n$.

Our results at the incident (scattered) electron energy $E_e = 1$ GeV ($E' = 827$ MeV), the electron scattering angle $\theta_e = 50^\circ$, $q = 788$ MeV/c and $E_{\text{np}}^{26} = 13.2$ MeV are displayed in the left part of Fig. 3. The right part of Fig. 3 corresponds to the MIT kinematics [4]. As it is seen from Fig. 3, the observable $P_x$ depends on the choice of $G_E^n$ at proton emission angles $\theta$ close to the limiting angle $\theta_{\text{lim}} = 90^\circ$ (parallel kinematics for recoil neutrons).
Fig. 3- Proton polarization components versus the $G_E^n$ model. The curves have been calculated for MEC /2/ with $\lambda = 4m_\pi$: solid-with $G_E^n /5/$, dashed-with $G_E^n = 0$.

Besides, we find here a rather weak sensitivity of $P_X$ to the FSI and MEC effects. Yet, the extraction of a reliable information on $G_E^n$ under these kinematic conditions will be a complicated problem. In fact, in this case $P_X$ takes too small values (a few percent) and the outgoing proton energy becomes too low. In our opinion, of great interest is the study of the angular dependences similar to the one shown in Fig. 3, where the component $P_Y$ undergoes qualitative changes on replacing $G_E^n = 0$ by $G_E^n /5/$. Therefore, precise measurements of the component $P_Y$ may help to see a difference between various models for the neutron electric FF.

REFERENCES