MEASUREMENTS OF D-STATES OF LIGHT NUCLEI BY TRANSFER REACTIONS * **

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This is a review paper on the investigations of the D-state component in few-body systems.

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1. Introduction

Many present experimental and theoretical investigations have focused on the D-state admixtures to the ground state wavefunction of the few-nucleon systems. The presence of these non-spherical components is a direct manifestation of the NN tensor interaction which is a crucial part of the nuclear force accounting for about 70% of the deuteron binding interaction and 40–50% of the binding for the three- and four-nucleon systems. Theoretical calculations use Faddeev-type equations for Hamiltonians based on two- and three-body models which are solved to calculate properties of few-body systems such as binding energies, radii and D-state probabilities. The measurement of the D-state observables therefore enables a comparison between experimental and theoretical models.

I will attempt to give a brief summary on the status of measurements of D-states in few-nucleon systems of $A \leq 6$. These studies were performed in recent years by the Nuclear Physics Group of the University of North Carolina at Chapel Hill.

The most effective method used to investigate the D-state properties in light nuclei is a measurement of tensor analyzing powers (TAP) in transfer

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reactions using a low-energy polarized beam. TAP are sensitive to the sign and value of the S- and D-state parts of the bound-state wavefunctions of the projectile and exiting particle so their measurement determines the asymptotic ratio η, characterizing the D- and S-state wavefunctions.

2. D-state for the nuclei with $A \leq 4$

The D-state in light nuclei is exhibited in different ways, for example as the existence of non-zero deuteron quadrupole moment ($Q = 0.2859(3)\,\mathrm{fm}^2$). It implies that the deuteron ground state wavefunction contains the $L = 2$ component. Unlike the deuteron, the three- and four-nucleon systems do not possess a measurable spectroscopic quadrupole moment. However, the wave-functions of $A = 3$ and 4 nuclei also contain the D-state component. In the last three years η was determined for $A = 3$ nuclei from comparisons of experimental angular distributions of TAP with the predictions of finite-range DWBA calculations. The radial wave function $U_L(r)$ with the relative orbital angular momentum L between the two fragments behaves in the asymptotic region as:

$$U_L(r) = N_L U_{NL}(r) \xrightarrow[r \to \infty]{} \frac{N_L}{\alpha r} W_{-\zeta, L+\frac{1}{2}}(2\alpha r), \tag{1}$$

where $W_{-\zeta,L+\frac{1}{2}}$ is a Whittaker function, ζ and α are the Coulomb parameter and the wave number, respectively. The asymptotic $\frac{D}{S}$ state ratio, η, is defined as $\eta = \frac{N_2}{N_0}$.

The current status of measurements of η along with bound state properties of light nuclei is shown in Table I.

TABLE I

NUCLEUS	J^π	E_B [MeV]	Q [fm^2]	$\eta \pm \Delta\eta$
^{2}H	1^+	2.22	+0.286	0.0256 ± 0.0004 [1]
^{3}H	$\frac{1}{2}^+$	8.48	0	0.0411 ± 0.0013 [2]
^{3}He	$\frac{1}{2}^+$	7.76	0	0.0386 ± 0.0045 [3]
^{4}He	0^+	28.0	0	0.0221 ± 0.0045 [4]
^{6}Li	1^+	32.0	−0.064	?

Values of η listed in the last column were extracted from TAP measurements in transfer reactions induced by polarized deuterons. For example, this method was succesfully applied to measure η for the triton [2]. The tensor analyzing powers A_{zz} were measured in $(\vec{d},t)$ reactions on ^{95}Mo,

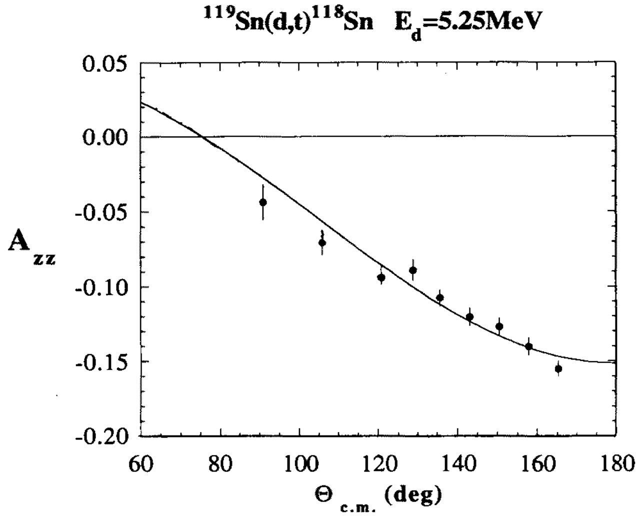

Fig. 1. Angular distributions of A_{zz} for the ^{119}Sn$(\vec{d},t)^{120}$Sn reaction at 5.25 MeV. The solid curve is an exact, finite-range DWBA calculation using the best fit value of η_t.

^{119}Sn, ^{149}Sm and ^{206}Pb targets at sub-Coulomb energies. Beam of polarized deuterons was produced by the high intensity Atomic Beam Polarized Ion Source at the Triangle Universities Nuclear Laboratory. The seven individual η values were extracted by minimizing the χ^2 parameter between calculated and measured TAP and then by computing a weighted average the final η_t value was obtained. Figure 1 shows an example of the A_{zz} measurement for ^{119}Sn$(\vec{d},t)^{120}$Sn reaction. Similar analysis was also performed for ^{3}He [3]. These experimental determinations of the η values (see Table I) agree with the recent two- and three-body theoretical calculations of Kievsky [5] who obtained η for the triton and for ^{3}He equal to 0.0430 and 0.0400, respectively.

3. D-state for ^{6}Li

The situation with ^{6}Li nucleus is different. Its quadrupole moment is very small and negative while most theoretical calculations predict Q between +0.25 fm^2 and +0.58fm^2 [6]. The D-state component of ^{6}Li exists in two different cluster configurations: $\alpha - d$ and ^{3}H$-^3$He. So far, only the first configuration was investigated in detail. The existing theoretical and experimental determinations of the η parameter are contradictory. For example, from the data on elastic and inelastic scattering of polarized ^{6}Li from heavy targets Nishioka *et al.* [7] extracted $\eta = -0.014$ by adjusting the amplitude of the D-state component to reproduce ^{6}Li quadrupole moment. Lehman *et al.* [8] used three-body models (αnp) to predict $\eta = +0.0194$ or $\eta = +0.0169$ depending on $\alpha - N$ potential used. From analysis of elastic $\alpha + d$ scattering Bornand *et al.* [9] extracted $\eta = +0.005 \pm 0.017$. From the analysis of TAP in $^6\mathrm{Li}(\vec{d}, \alpha)^4\mathrm{He}$ Santos *et al.* [10] obtained a negative value of η in a range between -0.015 and -0.010.

The goal of the experiment currently underway is to determine η from analysis of TAP in $(^6\vec{\mathrm{Li}}, d)$ and $(^6\vec{\mathrm{Li}}, \alpha)$ reactions on heavy targets. In these reactions the $\alpha + d$ cluster configuration in ^{6}Li is probed by studying transitions which involve the $< \alpha d|^6\mathrm{Li}>$ overlap in the DWBA transition amplitude.

Preliminary DWBA calculations for the $(^6\vec{\mathrm{Li}}, d)$ reaction predict very large sensitivity of TAP to the sign and magnitude of η. The measurements of A_{zz} and A_{xz} at the $^{58}\mathrm{Ni}(^6\vec{\mathrm{Li}}, d)^{62}\mathrm{Zn}$ reaction at $E_{\mathrm{lab}} = 34$ MeV were started last year at the Florida State University using ^{6}Li polarized ion source and the tandem accelerator. Data were taken in the angular range from $\Theta_{\mathrm{lab}} = 6.5^o$ to 40^o with four silicon detector telescopes. The analyzing powers were measured for the ground state and the first two excited states of ^{62}Zn. Preliminary results show that the A_{zz} values are very small and negative what indicates that η is also very small and negative. More extensive theoretical calculations are underway and further experiments are planned for the near future.

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