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Author: Beata Kozłowska

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

B. Kozłowska

Institute of Physics, Silesian University
Uniwersytecka 4, 40-007 Katowice, Poland
and Triangle Universities Nuclear Laboratory
Durham, North Carolina 27708, USA

(Received December 10, 1996)

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

PACS numbers: 21.45. +v, 24.50. +g, 24.70. +s, 25.45. Hi

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

* Presented at the XXXI Zakopane School of Physics, Zakopane, Poland, September 3–11, 1996.
** Work supported by USDOE Grant No. DE-FG05-88ER40442.

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,

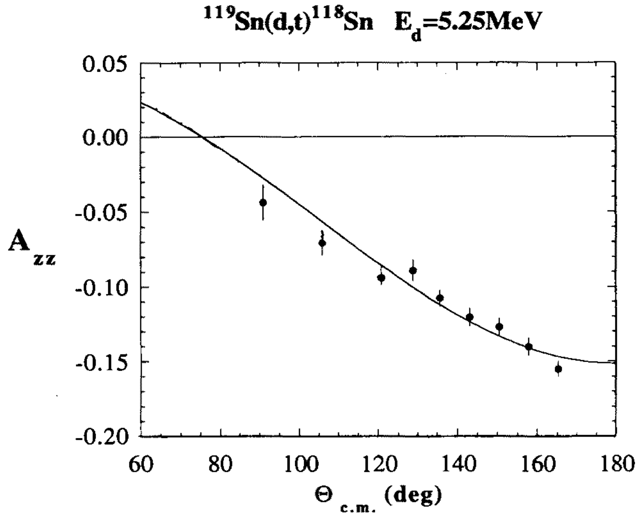

Fig. 1. Angular distributions of A_{zz} for the $^{119}\mathrm{Sn}(\vec{d},t)^{120}\mathrm{Sn}$ reaction at 5.25 MeV. The solid curve is an exact, finite-range DWBA calculation using the best fit value of η_t.

^{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 $^{119}\mathrm{Sn}(\vec{d},t)^{120}\mathrm{Sn}$ 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.

Collaboration with and advice of Prof. Ed Ludwig, Prof. Hugon Karwowski, Dr. Zeid Ayer, Prof. Ana Eiro and Mr. Kevin Veal are gratefully acknowledged.

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