TENSOR A_{yy} AND VECTOR A_y ANALYZING POWERS FOR $d\ d \rightarrow ^3H\ p$ AND $d\ d \rightarrow ^3He\ n$ REACTIONS AT 270 MEV

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Abstract

The high-momentum structure of the ^3He, ^3H and deuteron in the experiment with polarized deuteron beam performed at E_d = 270 MeV at RIKEN, Japan, in December 2000, was investigated. For this purpose the angular dependence of the tensor and vector analyzing powers were measured for the reactions $d\ d \rightarrow {}^3H\ p$ and $d\ d \rightarrow {}^3He\ n$ over full angular range. In this report, the results on the tensor A_{yy} and vector A_y analyzing powers are presented in the angular range $0° - 110°$ c.m.s.

Introduction

The structure of light nuclei has been extensively investigated over the last few decades using both electromagnetic and hadronic probes. Simple reactions at short internucleonic distances (or at large internal momenta) with one-nucleon-exchange (ONE) mechanism are $d\ p \rightarrow p\ d$ [1, 2], $d\ {}^3He \rightarrow p\ {}^4He$ [3, 4] or $d\ {}^3He \rightarrow {}^3He\ d$ [5]. In the framework of ONE approximation the polarization observables of these reactions are expressed in terms of the D/S-waves ratios in these nuclei. However, polarization observables and calculation within ONE approximation with the standard deuteron and ^3He wave functions strongly differ even at relatively small internal momenta ($\sim$ 200 MeV/c). These discrepancies may be due to a non-adequate description of the light nucleus spin structure at short distances, as well as by the importance of mechanism other than ONE. Therefore, the polarization data sensitive to the spin structure of deuteron and $^3He(^3H)$ are of great importance.

The $d\ d \rightarrow {}^3He\ n$ ($^3H\ p$) process also falls into the class of ONE reactions. This reaction can be described by the sum of two diagrams according to the symmetry of the initial state. The analysis of the polarization phenomena in the $d\ d \rightarrow {}^3He\ n$ reaction in the collinear geometry, where ^3He and deuteron beam have the same direction of momentum in c.m., was performed in [6]. Under these kinematical conditions, one of the two diagrams is strongly suppressed by the fast decrease in either the deuteron or ^3He wave functions with increasing relative momenta (at incident deuteron momenta higher than 200 MeV/c). Therefore the $d\ d \rightarrow ^3 He\ n$ ($^3H\ p$) reaction may be used to study the ^3He (^3H) and deuteron spin structures at short distancies.

Since ^3He and ^3H consist of $2np + 1pp$ pairs and $2np + 1nn$ pairs, respectively, the difference in their observables can be treated in terms of Charge Symmetry Breaking (CSB). Even the binding energies difference for these both nuclei is not well understood (see review [7] and references therein). Therefore the measurements of the polarization observables, which are not sensitive to the first order Coulomb corrections in the range of the internal momenta, where the exchanges by the ρ, ω etc. mesons are significant, can provide information on the nature of CSB.

Experiment

The polarized beam of deuteron was used for the measurement of the tensor and the vector analyzing powers in the $d\ d \rightarrow ^3H\ p$ ($^3He\ n$) reaction at RIKEN Accelerator Research Facility (RARF) (see Fig.1). The polarized ion source (PIS) provided beams with the different tensor and vector polarizations. The direction of symmetric axis of the beam polarization was controlled with a Wien filter located at the exit of PIS.

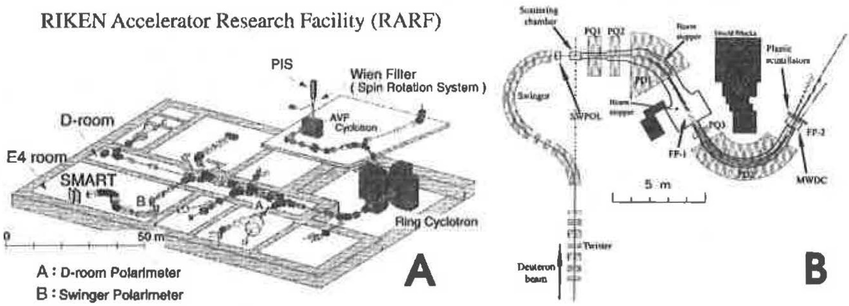

Figure 1: A) RIKEN Accelerator Research Facility (RARF), B) SMART spectrograph

We used four different spin modes whose ideal magnitudes of polarizations are

$$\text{mode } 0:(p_Z,p_{ZZ}) = (0,0), \quad (1)$$
$$\text{mode } 1:(p_Z,p_{ZZ}) = (0,-2), \quad (2)$$
$$\text{mode } 2:(p_Z,p_{ZZ}) = (-2/3,0), \quad (3)$$
$$\text{mode } 3:(p_Z,p_{ZZ}) = (1/3,1). \quad (4)$$

where p_Z (p_{ZZ}) denotes deuteron vector (tensor) beam polarization with respect to their cylindrically symmetric axis Z. The mode 0 - unpolarized mode, mode 1 - pure tensor mode, mode 2 - pure vector mode and mode 3 is mixed mode.

The obtained polarization values were $\sim$ 75% of the ideal values. The polarized deuteron beam was accelerated up to 270 MeV by the combination of the AVF cyclotron and Ring cyclotron. The beam polarizations were measured with D-room polarimeter (DroomPOL) located at D-room and Swinger polarimeter (SWPOL) placed just before the target. D-room polarimeter measured the polarization of deuteron beam during whole experiment. Swinger polarimeter measured the polarization in the beginning and at the end of each setting of the Swinger.

Both polarimeters utilize $d+p$ elastic scattering for polarimetry and value of polarization were derived using known analyzing powers A_y, A_{yy}, A_{xx} and A_{xz} [8] [9].

Deuterated polyethylene (CD_2) sheets [19] with 72 and 32 mg/cm^2 were used as a target and carbon foil with 34mg/cm^2 was used for measurement of background spectra.

The scattering angle of the polarized deuteron beam was controlled by rotating the Swinger. Scattered particles (^3H, ^3He or p) were momentum analyzed with quadrupole and dipole magnets (Q-Q-D-Q-D) and detected with multiwire drift chamber (MWDC) followed by the three plastic scintillators at the second focal plane. There are two focal planes, FP1 and FP2. MWDC placed at the focal plane FP2 has used as the coordinate detector. They provide the energy resolution $\sim$ 300 keV.

Detection and analysis

Criteries used for the selection of the scattered particles ^3H, ^3He or proton from the reaction $d\ d \to {}^3H\ p$ ($d\ d \to {}^3He\ n$) are the following.

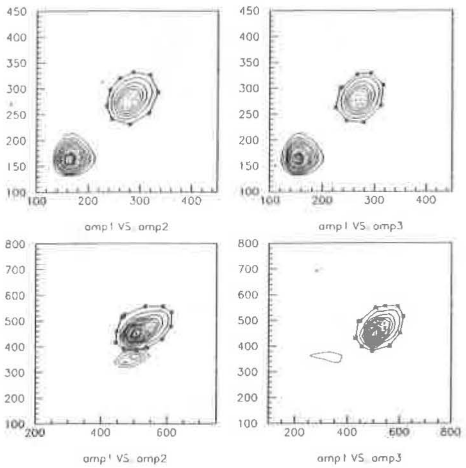

Figure 2: Amplitude correlation plots

Particle must be registered in the all three scintillation detectors and it was selected by the correlation of the energy losses in the 1st and the 2nd and the 1st and the 3rd scintillation detectors. Typical examples of 2-dimensional plots and imposed gates(solid curves) for the particle identification is in Fig. 2. Up-left and up-right are the amplitude correlation plots for ^3H, down-left and down-right are amplitude correlation plots for ^3He.

Radio Frequency signal of the cyclotron (RF-TDC) must be synchronized with the signals from the plastic scintillators.

The main source of the background was ^3He, ^3H and protons from the $d+{}^{12}C$ interaction. The number of useful events were obtained by the subtraction of the momenta spectra on the CD_2 and C foils.

To obtain the analyzing powers A_y and A_{yy} for the $d\ d \to {}^3H\ p({}^3He\ n)$ reactions we used the asymmetries and beam polarization values for the three different spin modes:

$$N^1_{exp}(\Theta_{cm}) = 1 + \frac{1}{2}p^1_{yy}A_{yy}(\Theta_{cm}), \quad (5)$$

$$N^2_{exp}(\Theta_{cm}) = 1 + \frac{3}{2}p^2_{y}A_{y}(\Theta_{cm}), \quad (6)$$

$$N^3_{exp}(\Theta_{cm}) = 1 + \frac{3}{2}p^3_y A_y(\Theta_{cm}) + \frac{1}{2}p^3_{yy} A_{yy}(\Theta_{cm}), \tag{7}$$

where N^1_{exp}, N^2_{exp} and N^3_{exp} are the asymmetries for the 1st, 2nd and 3rd mode and p^1_{yy}, p^3_{yy} (p^2_y, p^3_y) are tensor (vector) polarizations for the first (second) and the third mode.

Results and discussion

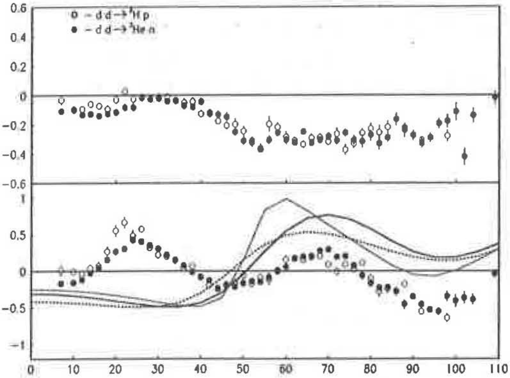

Figure 3: The results for the vector A_y and tensor A_{yy} analyzing powers.

The results for the vector A_y and tensor A_{yy} analyzing powers and the results for the ONE calculations for the angular distributions A_{yy} in angular range $0° - 110°$ in the centre-of-mass frame at energy E_d = 270 MeV are presented in Fig. 3.

The open and filled circles are for case of the ^3H p and ^3He n channels, respectively. The solid, dot-dashed and long-dashed curves are the results of ONE calculations [11] using Urbana [12], Paris [13] and Reid soft core [14] ^3He wave functions, respectively.

In the ONE approximation the vector analyzing power A_y is equal to zero, but in the experimental results we see some structures. These results will be a clue to the reaction mechanisms beyond the ONE model.

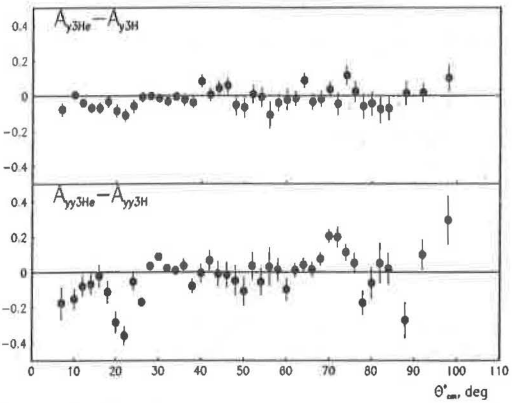

Figure 4: The $A_{y3H} - A_{y3He}$ and $A_{yy3H} - A_{yy3He}$ difference.

ONE calculations predict that the tensor analyzing power at forward angles are sensitive to the structure ^3H (^3He), but they are remarkable deviate from the experimental results. These results imply that there may be a problem in the realistic ^3H (^3He) wave functions used in the ONE calculations.

The experimental data on A_{yy} for these reactions shows sensitivity to the spin structure of deuteron at backward angles.

The experimental results for the ^3H and ^3He at angles larger than 30° are in the agreement within achieved errors. At smaller angles the difference in the analyzing powers is observed, however these results require further investigation of the systematics. Therefore at the moment, we cannot conclude that the effect of charge symmetry breaking was observed (see Fig. 4).

Conclusions

The results for the tensor A_{yy} and vector A_y analyzing power for $d\ d \to {}^3H\ p$ and $d\ d \to {}^3He\ n$ at energy $E_d = 270$ MeV are obtained.

ONE calculations predict that the tensor analyzing power at forward angles are sensitive to the structure ${}^3H$ (${}^3He$), but they are remarkable deviate from the experimental results. In the ONE approximation the vector analyzing power A_y equals to zero, but we see some structures in the experimental results. ONE model.

The experimental results for the ${}^3H$ and ${}^3He$ at angles larger than 30° are in the agreement within achieved errors. At smaller angles the difference in the analyzing powers is observed, however these results require further investigation of the systematics.

References

[1] N. Sakamoto, H. Okamura, T.Uesaka *et al.*, Phys. Lett. **B367** 60 (1996).

[2] H. Sakai, K. Sekiguchi, H. Witala *et al.*, Rev. Lett. **84** 5288 (2000).

[3] T. Uesaka, H. Sakai, H. Okamura *et al.*, Phys. Lett. **467** 199 (1999).

[4] T. Uesaka, H. Sakai, H. Okamura *et al.*, Few-body syst. Suppl. **12** 497 (2000).

[5] M.Tanifuji *et al.*, Phys.Rev. **C61** 024602 (2000).

[6] V. P. Ladygin, N. B. Ladygina, Yad. Fiz **59** 828 (1996) [Phys. At. Nucl. **59**, 789 (1996)].

[7] G. A. Miller, B. M. K. Nefkens and I. Šlaus, Phys. Rep **194**, 1 (1990).

[8] N. Sakamoto, Doctor Thesis, University of Tokyo (1996).

[9] T. Uesaka et al., Riken Accel. Prog. Rep. **33**, 153 (2000).

[10] Y. Maeda, H. Sakai, K. Hatanaka and A. Tamii, Nucl. Instr. and Meth. in Phys. Res. A **490**, 518 (2002).

[11] V. P. Ladygin *et al.*, Part. Nucl. Lett. **3[100]-2000**, 74 (2000).

[12] R. Schiavilla *et al.*, Nucl. Phys. **A449**, 219 (1986).

[13] J. M. Laget *et al.*, Nucl. Phys. **A370**, 479 (1981).

[14] F. D. Santos *et al.*, Phys. Rev. **C19**, 238 (1979).

Discussion

Q. (V. Ziskin): How was the deuterium beam polarization measured?

A. The deuteron beam polarization was measured on the base of d+p elastic scattering.

Q. (D. Nikolenko, BINP, Novosibirsk): What type of calculation for comparison with your data you show?

A. The data were compared with the prediction of one-nucleon-exchange.