MEASUREMENTS OF THE TENSOR A_{xx}, A_{yy}, A_{xz} AND VECTOR A_y ANALYZING POWERS FOR THE $d + d \to {}^3H + p$ AND $d + d \to {}^3He + n$ REACTIONS AT 270 MeV

M. Janek[1,2†], T. Saito[3], V.P. Ladygin[1], M. Hatano[3], A.Yu. Isupov[1], H. Kato[3], N.B. Ladygina[1], A.I. Malakhov[1], Y. Maeda[3], S. Nedev[4], J. Nishikawa[5], H. Okamura[5], T. Onishi[6], S.G. Reznikov[1], H. Sakai[3], N. Sakamoto[6], S. Sakoda[3], Y. Satou[3], K. Sekiguchi[6], K. Suda[5], N. Uchigashima[3], T. Uesaka[3], A. Tamii[3], T.A. Vasiliev[1], K. Yako[3]

(1) *LHE-JINR, 141-980 Dubna, Moscow region, Russia*
(2) *University of P.J. Šafárik, 041-54 Košice, Slovakia*
(3) *Department of Physics, University of Tokyo, Tokyo 113-0033, Japan*
(4) *University of Chemical Technology and Metallurgy, Sofia, Bulgaria*
(5) *Department of Physics, Saitama University, Saitama 338-8570, Japan*
(6) *RIKEN, 351-0198 Wako, Japan*
† *E-mail: janek@sunhe.jinr.ru*

Abstract

The experimental results on the tensor A_{xx}, A_{yy}, A_{xz} and vector A_y analyzing powers at $E_d = 270\ MeV$ for the d + d → ^{3}H + p and d + d → ^{3}He + n reaction are presented. The energy dependence of the tensor analyzing power T_{20} at a zero degree as well as the angular dependences of the tensor analyzing powers T_{20} and T_{22} are shown. The ^{3}He - ^{3}H analyzing powers difference are presented, but the results require further investigation at small angles.

1. Introduction

The structure of light nuclei can be investigated by electromagnetic and hadronic probes.

Simple reactions with large transfer momentum (short distances) and one-nucleon-exchange (ONE) mechanism are d + p → p + d [1]-[2], d + ^{3}He → p + ^{4}He [3]-[4] or d + ^{3} He → ^{3} He + 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, the remarkable deviation of the polarization observables on the ONE predictions using standart deuteron and ^3He wave functions occurs even at relatively small internal momenta of $\approx 200 MeV/c$. Such a discrepancy can be due to the non-adequative description of the light nuclei structure at short distances, as well as to the importance of the mechanisms in addition to ONE.

2. Experiment

The experiment was performed at RIKEN Accelerator Research Facility (RARF) (see Fig. 1). The direction of symmetric axis of the beam polarization was controlled with a Wien filter located at the exit of polarized ion source (PIS).

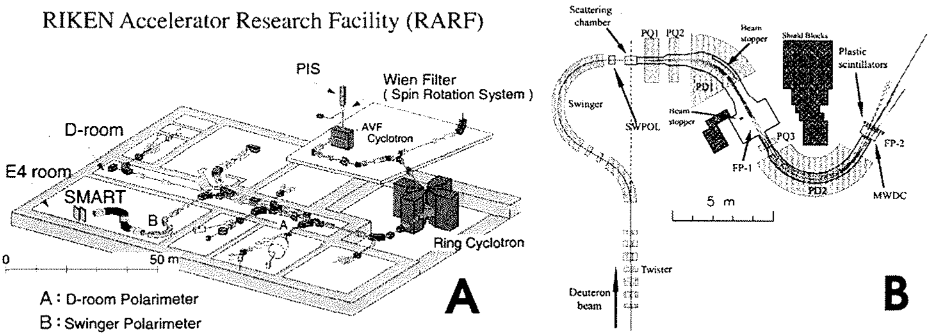

Figure 1: A) RIKEN Accelerator Research Facility (RARF), B) SMART spectrograph

The deuteron vector (p_Z) and tensor (p_{ZZ}) beam polarization with respect to their cylindrically symmetric axis Z are defined by

$$p_Z = N_+ - N_-, \tag{1}$$
$$p_{ZZ} = N_+ + N_- - 2N_0, \tag{2}$$

where N_+, N_- and N_0 denotes the fractions of deuteron beam in magnetic substates +1, -1 and 0, respectively. In this experiment, four spin modes were used, whose ideal magnitudes of polarizations are

$$\text{mode 0: } (p_Z, p_{ZZ}) = (0, 0), \tag{3}$$
$$\text{mode 1: } (p_Z, p_{ZZ}) = (0, -2), \tag{4}$$
$$\text{mode 2: } (p_Z, p_{ZZ}) = (-2/3, 0), \tag{5}$$
$$\text{mode 3: } (p_Z, p_{ZZ}) = (1/3, 1). \tag{6}$$

The mode 0 - unpolarized mode, mode 1 - pure tensor mode, mode 2 - pure vector mode and mode 3 is the 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) just before the target. 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} [6] [7].

Deuterated polyethylene (CD_2) sheets with 0.72 and 0.32 mg/mm^2 were used as a target and carbon foil with 0.34 mg/mm^2 was used for measurement of background spectra.

The scattering angle of the polarized deuteron beam was controlled by rotating of the Swinger. Scattered particles (^{3}H, ^{3}He or p) were momentum analyzed with quadrupole and dipole magnets (Q-Q-D-Q-D) and detected with MWDC followed by the three plastic scintillators at the second focal plane.

Criteria used for the identification of the scattered particles ^{3}H, ^{3}He or proton from the reaction d + d → ^{3}H + p (d + d → ^{3}He + n) are the following. 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. Radio frequency signal of the cyclotron was used as a reference of time-of-flight measurement.

The main source of the background was ^{3}He, ^{3}H 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, A_{yy}, A_{xx} and A_{xz} for the d + d → ^{3} H + p (^{3}He + n) reactions we used the asymmetries and beam polarization values for the three different spin modes.

3. Results and discussion

The tensor analyzing power T_{20} at Θ_{cm} = 0° or 180°(see Fig. 2) is given by [8], [9]

$$T_{20} = \frac{1}{\sqrt{2}} \frac{2\sqrt{2}u(k)w(k) - w(k)^2}{u(k)^2 + w(k)^2}, \tag{7}$$

where $u(k)$ and $w(k)$ are the S- and D-wave functions for ^{3}He (^{3}H) or deuteron for Θ_{cm} = 0° or 180°, respectively.

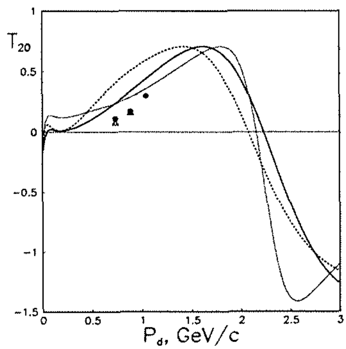

Figure 2: Tensor analyzing power T_{20} at Θ_{cm} = 0° at E_d= 270, 200 and 140 MeV [10]. The ^{3}He + n (^{3}H + p) channel are presented by solid and open symbols, respectively. The solid and dashed curves are calculated using Urbana ^{3}He wave function

One can see that the ONE predictions reproduce incident energy dependence and the sign of the experimental data. Since the T_{20} at 0° is directly connected with D/S ratio of ^{3}He (^{3}H) (1), the sign of T_{20} at 0° reflects the relative sign of wave functions $u(k)$ and $w(k)$ for ^{3}He(^{3}H).

The angular dependences for the tensor A_{xx}, A_{yy}, A_{xz} and vector A_y analyzing powers at energy E_d=270 MeV are presented in Fig. 3.

ONE calculations predict that the vector analyzing power A_y equals to zero, but some structures are observed in the experimental results. The angular distribution of A_y indicates the necessity of description of its reaction mechanism beyond the ONE.

In the ONE calculations the tensor analyzing powers at forward angles are sensitive to the structure ^{3}H (^{3}He) but they remarkably deviate from the experimental results. These results may imply that there is a problem in the realistic ^{3}H (^{3}He) wave functions used in the ONE calculations.

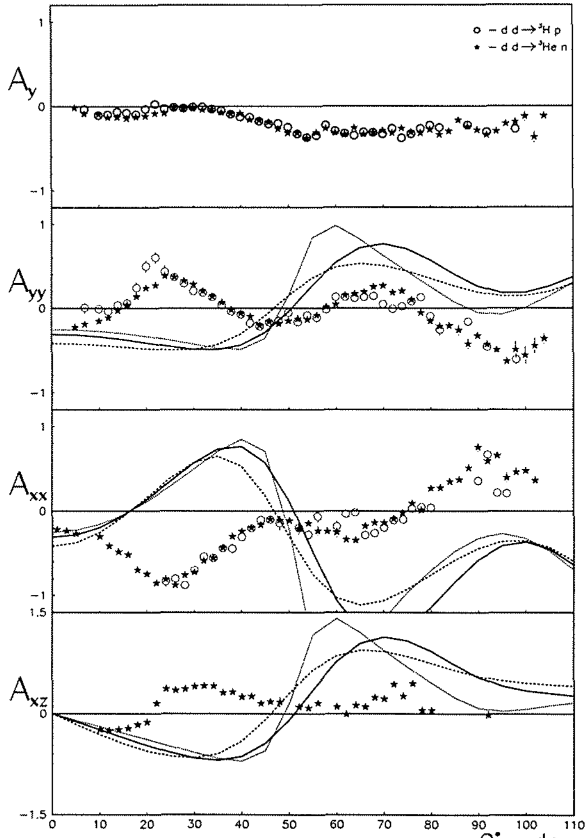

Figure 3: The results for the vector A_y and tensor A_{yy}, A_{xx} and A_{xz} analyzing powers in the centre-of-mass frame at energy E_d=270 MeV. The open and solid circles are for case of the ^{3}H + p and ^{3}He + n channels, respectively. The solid, dot-dashed and long-dashed curves are the results of ONE calculations [8] using Urbana [11], Paris [12] and Reid soft core [13] ^{3}He wave functions, respectively

The tensor analyzing powers T_{20} and T_{22} can be expressed via A_{xx} and A_{yy} as

$$T_{20} = \frac{1}{\sqrt{2}}(A_{xx} + A_{yy}), \tag{8}$$

$$T_{22} = \frac{(A_{xx} - A_{yy})}{2\sqrt{3}}. \tag{9}$$

The angular dependences for the tensor T_{20} and T_{22} analyzing powers at energy E_d=270 MeV are presented in Fig. 4.

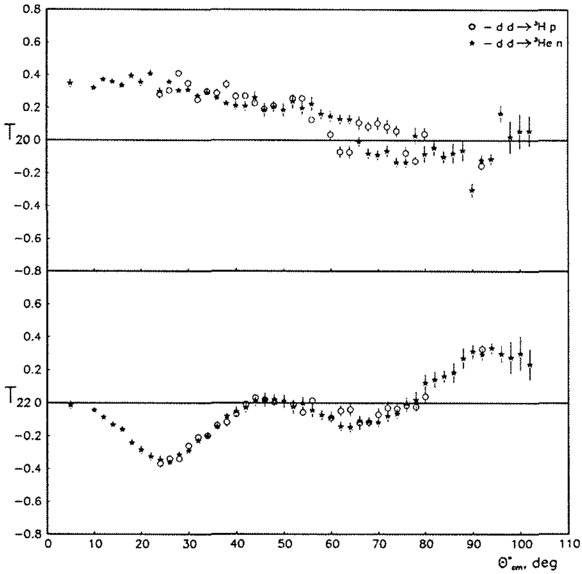

Figure 4: Angular dependences of tensor analyzing powers T_{20} and T_{22} at E_d= 270 MeV. The $^3He\ n$ ($^3H\ p$) channel are presented by filled (opened) symbols

Tensor analyzing power T_{20} at small angles have the same sign and approximatelly the same values as the T_{20} at zero degree [10]. In this region the T_{20} values are approximatelly constant. The T_{20} intersects the axis at $\sim$ 60 degrees (internal impulse $\sim$ 600 MeV/c).

The experimental results for the ^{3}H and ^{3}He at angles larger than 30° are in the agreement within statistical 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 (Fig. 5).

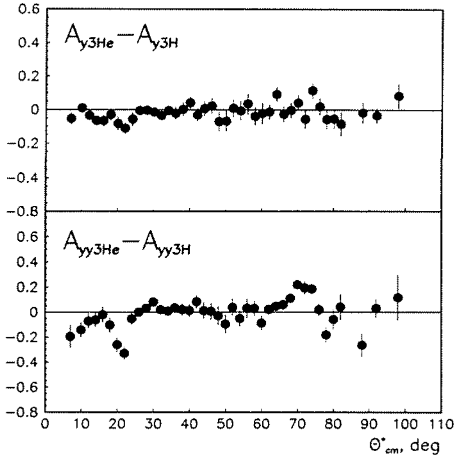

Figure 5: $A_{y3He} - A_{y3H}$ and $A_{yy3He} - A_{yy3H}$ difference

Acknowledgements

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