# Measurement of differential cross sections and vector analyzing powers for the $\vec{n}d$ scattering at 250 MeV

Y. Maeda[a], H. Sakai[a], K. Hatanaka[c], H. Okamura[b], A. Tamii[a], T. Wakasa[c], K. Yako[a], K. Sekiguchi[a], S. Sakoda[a], J. Kamiya[c], K. Suda[b], H. Kato[a], M. Hatano[a], D. Hirooka[c], T. Saito[a], N. Uchigashima[a], M.B. Greenfield[d], J. Rapaport[e]

[a] *Department of Physics, University of Tokyo, Tokyo 113-0033, Japan*
[b] *Department of Physics, Saitama University, Saitama 338-8570, Japan*
[c] *Research Center for Nuclear Physics (RCNP), Ibaraki, Osaka 567-0047, Japan*
[d] *Division of natural Science, International Christian University, Tokyo 181-8585, Japan*
[e] *Department of Physics, Ohio University, Athens, Ohio, 45701-2979, USA*

Recently the three-nucleon force (3NF) has been actively studied from both theoretical and experimental sides. 3NFs arise naturally in the standard meson exchange picture and its main ingredient is considered to be a $\Delta$ isobar excitation in an intermediate state. We have measured $\vec{d}p$ elastic scattering at $E_d$ = 270 MeV at RIKEN [1]. Faddeev calculations which include two-body nucleon-nucleon (NN) forces alone significantly underestimate the measured differential cross sections and vector analyzing powers in the backward angular region. Adding the Tucson-Melbourne (TM) 3NF leads to an excellent agreement with the data. These results are considered as clear signatures of 3NF effects.

However, since the inclusion of the Coulomb interaction into the calculation is difficult, 3NF effects have been discussed by the comparison between the $\vec{d}p$ data and the $\vec{d}n$ Faddeev calculations neglecting the Coulomb effect. The Coulomb effect is certainly dominant in the very forward angular region. In addition, it was pointed out that the Coulomb effect may remain even in the backward scattering region [2] where 3NF effects are expected to be large.

To study 3NF in a Coulomb-free system and to reach a decisive conclusion about 3NF, we have measured the differential cross sections and vector analyzing powers for the $\vec{n}d$ elastic scattering at 250 MeV.

We have carried out the measurement at the $(n,p)$ facility [3] at the Research Center for Nuclear Physics (RCNP). The polarized neutron beam was produced by the $^7$Li$(\vec{p},\vec{n})$ reaction at $E_p$ = 248 MeV. The thickness of the $^7$Li target was 580 mg/cm$^2$. The typical polarization of the neutron beam was 0.16 which was calculated from the proton beam polarization (0.6) and $D_{NN}$ (-0.28) of the reaction. We used self-produced four deuterized polyethylene ($CD_2$) foils with a thickness of 220 mg/cm$^2$ as deuteron targets. Recoil deuterons were momentum analyzed by the Large Acceptance Spectrometer (LAS) and were detected at the focal plane. We also measured the $C(n,d)$ reaction with natural carbon targets (180 mg/cm$^2$ $\times$ 4) to subtract the events from carbon in the $CD_2$ target. Figure 1 shows the spectra of $(n,d)$ reactions at $\theta_{LAB}$ = 0° – 2°. Two sharp peaks are due to the $^2$H$(n,d)$n and $^{12}$C$(n,d)^{11}$B$(g.s.)$ reactions, respectively. We also measured the $\vec{n}p$ elastic scattering with $CH_2$ (190 mg/cm$^2$ $\times$ 4) targets. We determined the amount of neutrons at the target position and the acceptance of the LAS by comparing the results of $\vec{n}p$ measurements and the calculations with the program code SAID, then we extracted the absolute values of the differential

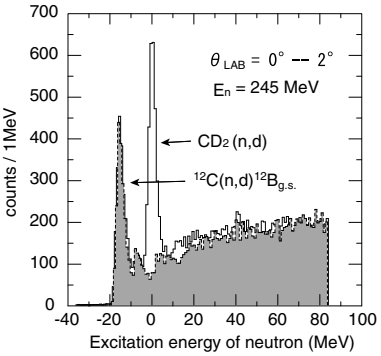


Figure 1: Excitation energy spectrum for the $CD_2(n,d)$ (solid lines) and $C(n,d)$ (hatched region) reactions at $E_n$ = 245 MeV.

cross sections.

The preliminary data of the differential cross sections and the vector analyzing powers are shown in Figure 2 by solid circles. The thin curves are the Faddeev calculations of $\vec{n}d$ elastic scattering using the CD-BONN potential (solid curve) and Argonne $v_{18}$ potential (AV18) (dashed curve) as NN interactions, respectively. By comparing these two calculations, the effect due to the uncertainty of the NN interaction is considered to be small. The thick curves are the calculations including 3NF [4]. The solid curves are the calculations with the CD-BONN + Tucson-Melbourne 3NF and the dashed curves are the one with the AV18 + Urbana 3NF. The calculations including 3NF slightly better reproduce but still underestimate the data. These discrepancies may be considered as an indication of relativistic effects [5, 6] which is not incorporated in the present calculations.

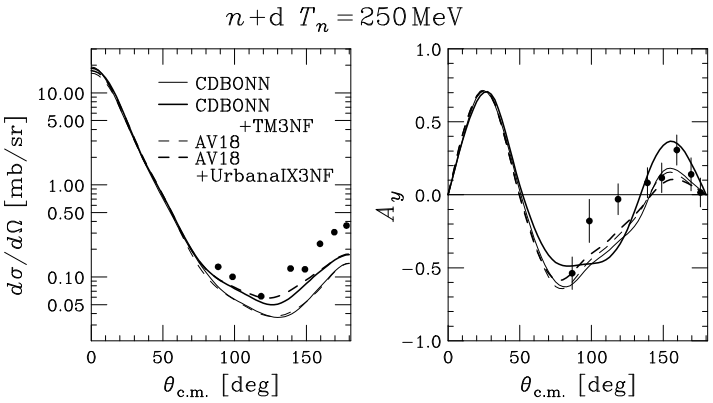


Figure 2: Differential cross sections and vector analyzing powers for the $\vec{n}d$ elastic scattering at $E_n$ = 245 MeV. The solid circles are the results of this experiment with statistical errors. The curves show the results of Faddeev calculations with CD-BONN potential (thin solid), AV18 potentials (thin dashed), CD-BONN potential including TM-3NF (thick solid) and AV18 potential including Urbana 3NF (thick dashed).

As for the vector analyzing powers, none of the calculations succeeded in explaining the angular distribution around $\theta_{cm} \sim 110°$. However, more statistics is required for precise discussions.

## Acknowledgement

We acknowledge Dr. H. Kamada for his valuable calculations. We would like to thank Dr. Izuru Daito for his advises about techniques of producing thin $CD_2$ targets. This project is supported by the Ministry of Education, Culture, Sports, Science and Technology of Japan with the Grant-in-Aid for Science Research No. 10304018.

## References

[1] H. Sakai *et al.*, Phys. Rev. Lett. **84**, 5288 (2000).
[2] Y. Koike, private communication.,
N. Sakamoto *et al.*, Phys. Lett. B **367**, 60 (1996).
[3] K. Yako *et al.*, Nucl. Phys. **A684**, 563c (2001).
[4] H. Kamada, private communication.
[5] H. Rohdjeß *et al.*, Phys. Rev. C **57**, 2111 (1998).
[6] H. Witała *et al.*, Phys. Rev. C **57**, 2111 (1998).