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# Measurements of the $\vec{n}d$ scattering at 250 MeV and three-nucleon forces

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The differential cross sections and the vector analyzing powers for the $nd$ elastic scattering at $E_n = 250$ MeV have been measured for the study of the three-nucleon force (3NF) effects in the Coulomb-free system. To cover a wide angular region, the experiments were performed by using two different methods at the $(n, p)$ facility and at the NTOF facility which constructed at the Research Center for Nuclear Physics (RCNP). The results were compared with theoretical predictions of the Faddeev calculations based on the modern nucleon-nucleon (NN) forces with the three-nucleon force (3NF). The inclusion of 3NFs leads to a good description of the cross section except for the backward angles. The results were also compared with the theoretical predictions with relativistic corrections. The direct data-to-data comparison of the cross sections of the $nd$ and $pd$ was performed.

## 1. INTRODUCTION

The study of three-nucleon force (3NF) properties in the three-nucleon continuum is one of the interesting problems for the few-nucleon system.

Recently, highly rich set of the data for the $dp$ elastic scattering at the deuteron energies of $E_d^{\rm lab} = 140 - 270$ MeV have become available [1]. The calculations with NN forces only fail to reproduce the data of cross sections and vector analyzing powers, but these

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discrepancies are filled by adding the $2\pi$ exchange 3NFs. These results support the prediction that the $Nd$ elastic scattering at intermediate energy is a good probe to study the 3NF effects. However, it should be noted that all discussions are made by the comparison between the precise $pd$ data and the rigorous $nd$ Faddeev calculations because performing the three-body calculation with the long-range Coulomb repulsion is extremely difficult.

To study the 3NF effects without uncertainties from the Coulomb force, we have carried out the $\vec{n}d$ elastic scattering at 250 MeV at RCNP. We measured the differential cross sections and vector analyzing powers for $\theta_{cm} = 10^\circ$ – $180^\circ$. To cover such a wide angular region, we applied two kinds of technique to perform the forward and the backward measurements, respectively.

## 2. EXPERIMENT

The Measurements for the backward angular region ($\theta_{cm} \geq 60^\circ$) were carried out at the $(n, p)$ facility [2] which was constructed at RCNP. The nearly mono-energetic polarized neutron beam was produced by the $^7$Li$(\vec{p}, \vec{n})^7$Be(g.s.+0.4 MeV) reaction at 250MeV. We used the self-supporting deuterated polyethylene ($CD_2$) sheets [3] with a thickness of 100 – 220 mg/cm$^2$ as the deuteron targets. The deuteron targets were mounted in the multi-wire drift chamber (MWDC). In this work, we also measured the $np$ elastic scattering for the normalization purpose. Then we used the polyethylene ($CH_2$) sheets with a thickness of 90 – 190 mg/cm$^2$ as proton targets. The recoil deuterons or protons were momentum analyzed by Large Acceptance Spectrometer (LAS).

The measurements for the forward angular region ($\theta_{cm} \leq 60^\circ$) were carried out at the neutron time-of flight (NTOF) facility [4] at RCNP. The polarized neutron beam was also produced by the $^7$Li$(\vec{p}, \vec{n})$ reaction. The produced neutrons bombarded the deuteron target which was located 2 m downstream from $^7$Li target. The deuterated liquid scintillator BC537 was used as the deuteron target. To remove the background events originating from the gamma rays, we introduced the $n\gamma$ discrimination method. The scattered neutrons run through 70 m distance and detected by the NPOL II. The energy of the scattered neutron was determined by the TOF technique. Since both deuteron and neutron were detected by the active deuteron target and the NPOL II, respectively, the coincidence measurements were performed.

## 3. RESULTS AND DISCUSSION

The results of the differential cross sections and vector analyzing powers are shown in figure 1 by solid circles and squares with statistical errors only. Dark (light) shaded bands represent the results of Faddeev calculations with (without) the Tucson-Melbourne99 3NF[5]. Solid line represent the calculation with AV18+UrbanaIX-3NF. Concerning about the differential cross sections, it can be seen that the calculations including 3NF better reproduce the data but still underestimate largely at backward angles. These discrepancies may be an indication of the relativistic effects[6] which are not taken into account in these calculations. The data of the vector analyzing powers contain large statistical errors but these are consistent with the $\vec{p}d$ data within the systematic error of the $\vec{n}d$ data. We can see that the calculations fail to reproduce the angular distribution of the data at $\theta_{cm}$ =110$^\circ$ ∼140$^\circ$.