Proc. 13th Int. Conf. on Nucleus-Nucleus Collisions
JPS Conf. Proc. **32**, 010042 (2020)
https://doi.org/10.7566/JPSCP.32.010042

Possible signature of tensor interactions observed via (p,dN) reaction at large momentum transfer

S.Terashima[1], L. Yu[1], H. J. Ong[2], I.Tanihata[1,2], S. Adachi[2], N. Aoi[2], P.Y. Chan[2], H. Fujioka[3], M. Fukuda[4], H. Geissel[5], G. Gey[2], E. Haetther[5], C. Iwamoto[2], H, Kamada,[6] T. Kawabata[3.4], X.Y. Le[1], H. Sakaguch[2], A. Sakaue[3], C. Scheidenberger[5], B.H. Sun[1], A.Tamii[2], T.L. Tang[2], D.T. Tran[2], T.F. Wang[1], Y. N. Watanabe[7], H. Weick[5], G.X. Zhang[1], and L.H. Zhu[1]

[1]*School of Physics, Beihang University, 100191 Beijing, China*
[2]*RCNP, Osaka University, Mihogaoka, Ibaraki, Osaka 567-0047, Japan*
[3]*Department of Physics, Kyoto University, Kyoto 606-8502, Japan*
[4]*Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*
[5]*GSI Helmholtzzentrum für Schwerionenforschung GmbH,, 64291 Darmstadt, Germany*
[6]*Department of Physics, Faculty of Engineering, Kyushu Institute of Technology, Kitakyushu 804-8550, 7, Japan*
[7]*Department of Physics, University of Tokyo, Tokyo 113-0033, Japan*
**E-mail: tera@buaa.edu.cnx*

(Received July 31, 2019)

We report observation of possible new evidence for tensor interactions from ^{16}O(*p*,*dN*) measurements at 392-MeV proton under quasi-free scattering kinematics but at scattering angle relevant to neutron pick up mechanism. The strong isospin dependence at large momentum transfer indicate the presence of high-momentum protons and neutrons induced by the tensor interactions in ^{16}O.

KEYWORDS: tensor interaction, quasi-free scattering

1. Introduction

High-momentum components in atomic nuclei are important for understanding the roles of noncentral nuclear interactions, such as the tensor interactions, beyond the single particle motion characterized by the Fermi momentum. The importance of the tensor interactions, which act mainly between a proton and a neutron in a nucleus, have been recognized from the binding energies of light particles such as the deuteron and alpha particle, and the presence of large D-wave mixing in the deuteron. Recent theoretical developments, particularly in ab initio–type calculations, enable treatment of high-momentum components directly including tensor interactions. An important feature in theoretical calculations is a strong spin-isospin character of a pair [1,2]. A coincidence measurement (*p,Nd*) of a nucleon *N* (*p* or *n*) associated with a deuteron emitted at a small angle has strong sensitivity to correlated pairs of nucleons whose relative momentum is large. In the (*p,Nd*) reaction, we can distinguish the spin isospin of the nucleon pairs *p-n*, and *n-n* by measuring the specific final state of the residue with good energy resolution. The pickup mechanism of a neutron dominates when a scattered deuteron is observed at small angles. If a reaction occurs with an (*S,T*)=(1,0) pair, both nucleons are removed and thus the final state of the residual should have *T*=0. If instead the *p-n* pair has (*S,T*)=(0,1), the final state should be *T*=1.

2. Experiment

The experiment was performed at the Research Center for Nuclear Physics (RCNP) cyclotron facility using the newly constructed GRAF (Grand-RAiden Forward mode) beam line [3]. Scattered deuterons were momentum analyzed by the high-resolution spectrometer Grand Raiden equipped with two drift chambers and a pair of plastic scintillators on the focal plane. The coincidence detector array were placed outside of scattering chamber at backward angles to cover the zero recoil momenta of ^{14}N and ^{14}O in the ^{16}O(*p,pd*) and ^{16}O(*p,nd*) reactions, respectively. Detailed information of experiment for (*p,pd*) and for neutron detector were described in Ref. [2] and Ref. [4].

The excitation energies were determined from the momentum vectors of the detected deuterons and protons, where a coplanar geometry between deuterons and protons was assumed. The achieved energy resolution in the (*p,pd*) reaction, about 1.6 MeV FWHM was dominated by the energy resolution of scintillators for protons. The (*p,d*) reaction at small angles is dominated by the pickup of high-momentum neutrons of correlated *p-n* pairs. The correlated protons are emitted with a high momentum at a backward angle, just like protons emitted in a backward angle in (*p,d*) elastic scattering. The importance of the pickup process increases with increasing scattering angle which is represented by the rise of the cross section. The 2.31-MeV state in ^{14}N is (*J,T*)=(0,1) and the 3.95-MeV state is (*J,T*)=(1,0), and thus they are suitable for the present study. The 3.95-MeV state was predominantly observed on the other hand, the 2.31-MeV state was observed weakly. It seems to be inconsistent with previous results at lower energy knockout reaction at 75 MeV [5]. In addition to the proton channel, the neutron channel of *(p.nd)* was measured with BOS^4 array [2]. Gamma-ray contaminants were removed by the pattern discriminations using both energy depositions and their balances of even or odd layers. After gamma-ray discrimination as well as charged particle rejection with the detectors before the BOS^4, an excitation energy spectrum was calculated as the same manner of (*p,pd*) reactions. Typical spectrum and contribution of accidental coincidence was shown in Fig. 1. A clear peak around the ground state of ^{14}O was observed on amounts of accidental contributions. The energy resolution, which depended on their kinetic energy varied from 6 MeV to 20 MeV FWHM. Due to the worse resolutions and their small cross sections, it is very difficult to identify the peaks separately. Thus, the cross sections of $^{16}O(p,nd)^{14}O$g.s. reaction were extracted by a peak fitting, where the response functions were estimated by the Monte-Carlo methods. Observed cross sections were much smaller than for the 3.95-MeV state, which was comparable with the 2.31-MeV state in $^{16}O(p,pd)$ reaction.

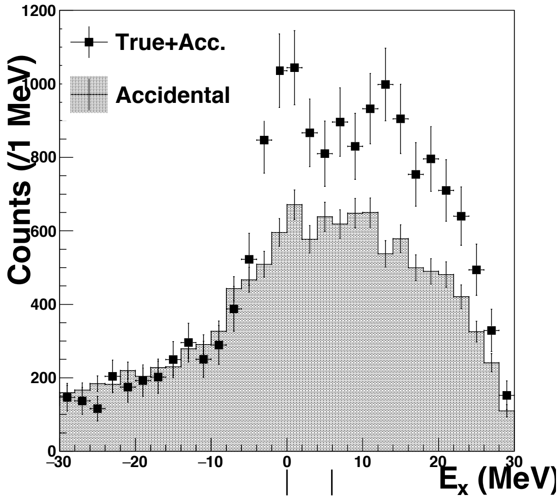

Fig. 1. The excitation energy spectrum of $^{16}O(p,nd)$ with accidental contributions.

3. Discussion and conclusion

The data were compared with distorted-wave impulse approximation (DWIA) calculations [6] with realistic elastic *d*(*p,p*)*d* and spin-flip reaction ‘*p-n*’(*p,p*)*d* and charge exchange ‘*n-n*’(*p,n*)*d* cross sections for d, *p-n*, and *n-n* channels. Here latter reactions were derived from the three-body break up reactions by Faddeev calculation with CD-Bonn interactions [7]. Because no reference exists for (*p,nd*) reaction at any energies, we compared the results with $(J,T)=(0,1)$ states of (*p,pd*) reactions. Their relative cross sections were well understood in the present DWIA as shown in Fig.2, besides the calculations with known spectroscopic amplitudes, obtained at lower energy deuteron knockout (*p,pd*) reaction, do not reproduce the observed ratio of cross sections between $(J,T)=(1,0)$ and $(J,T)=(0,1)$ states [2]. It indicates that $(J,T)=(1,0)$ component is dominated in *p-n* pairs at large relative momenta. The observed strong isospin dependence in the *p-n* pair and *n-n*

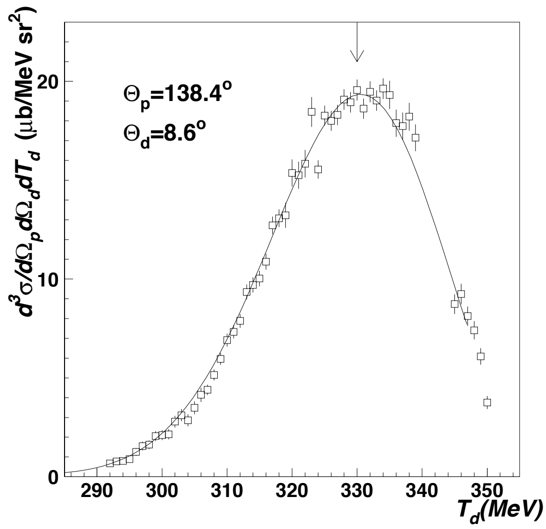

Fig. 2. The energy sharing distribution of 3.95 MeV state at $^{16}O(p,pd)$ with the DWIA calculation. The vertical scale of calculation was normalized at the minimum of recoil momenta given by the arrow.

pair indicates a presence of high-momentum neutron by the tensor interaction in ^{16}O.

The cross sections of the ^{16}O(*p,pd*) and ^{16}O(*p,nd*) the reactions were measured for 392-MeV incident protons with the coincidences between protons and neutrons at backward angles and deuterons at forward angles, where the neutron pickup reaction mechanism is dominant. The first and second excited states in the residual ^{14}N and the ground state of residue ^{14}O with L=0 transitions were compared with the DWIA calculations. A strong relative reduction of the first excited state cross section compared to that of the second excited state was observed, which is expected to be due to the tensor correlations. The DWIA calculations using the two-body interactions including tensor interactions qualitatively explained the reduction of the $(S,T)=(0,1)$ to $(S,T)=(1,0)$ ratio of the cross sections. The cross section of ground state with neutron coincidence was observed in same kinematics with much smaller cross sections, which is similar yield of the first excited state in ^{14}N and the ground state in ^{14}O. It is the first possible indication of isospin symmetry in high-momentum nucleon-pair in ^{16}O.

Acknowledgment

The authors thank the cyclotron crews at RCNP for their efforts to provide a clean and stable beam. The support of the P.R. China government and Beihang University under the Thousand Talent program is gratefully acknowledged. This work was partially supported by the National Natural Science Foundation of China under Contracts No. 11235002, No. 11375023, No. 11475014, and No. 11575018, and by the National Key R&D program of China (2016YFA0400504) and Hirose International Scholarship Foundation. The experiment was partly supported by a grant-in-aid program of the Japanese government under the Contracts No. 20244030 and No. 23224008. Theoretical calculations have been partly supported by the Polish National Science Centre under Grants No. 2016/22/M/ST2/00173 and No. 2016/21/D/ST2/01120.

References

[1] E. Piasetzky et al Phys. Rev. Lett. 97, 162504(2006)
[2] S. Terashima, et al., Phys. Rev. Lett. 121, 242501 (2018) and references therein.
[3] N. Kobayashi et al. submitted to EPJA
[4] L. Yu, S. Terashima, et al., Nucl. Inst. A866 (2017)118
[5] J. Y. Grossiord, et al., Phys. Rev. C 15, 843 (1977)
[6] N.S. Chant and P.G. Roos, Phys Rev. C 15, 57 (1977)
[7] W. Glöckle, H. Witała, D. Hüber, H. Kamada, and J. Golak Phys. Rep. 274, 107(1996)