Spin Mode in the Low-Energy (p, n) Reaction

I. 1 Spin Mode in the Low-Energy (p,n) Reaction

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I INTRODUCTION

The spin-isospin mode of excitation can be directly related to charge-exchange reactions such as (π^+, π^0), (p,n), (^{3}He,t), etc., while the magnetic excitation, in which spin-transfer takes place, is an area of high current interest. Quenching effects of nuclear magnetic properties have been extensively studied[1-6] and it seems established[7-9] that the observed Gamow-Teller strength is usually (25-50)% of the sum-rule limit. Meanwhile, the one-pion exchange also gives rise to a strong tensor interaction in the (τ, τ) channel. The tensor interaction can be studied in (p,n) reactions in which high-spin states are excited. Thus new data on high-spin unnatural-parity states, especially stretched particle-hole states may provide conspicuous informations for the nuclear excitation caused by particle-hole interactions, since the number of particle-hole excitations which can contribute to these states are severely restricted.

Stretched states have been studied so far in medium-energy electron scattering experiments at backward angles and (p,p') experiments. Lindgren et al.[10] have reported a systematic comparison of the (e,e') and (p,p') transition strengths for the excitation of unnatural-parity states of stretched configurations. Recently, such stretch states of $1\hbar\omega$ character have been observed in the (p,n) reactions on ^{24}Mg for the 6^- state[11] and on ^{16}O for the 4^- state[12,13].

In this report we present the observation of stretched 4^- states in ^{12}N and ^{16}F, which have the $[\pi d5/2 \nu p3/2^{-1}]_{4^-}$ configuration, by the (p,n) reactions at $E_p = 40$ MeV, and a 6^- state in ^{28}P, i.e. $[\pi f7/2, \nu d5/2^{-1}]_{6^-}$, at $E_p = 35$ MeV together with the results described in Ref. 11. The experiments were performed by using proton beams from the AVF cyclotron and the time-of flight facilities at Cyclotron and Radioisotope Center, Tohoku University. We have utilized a beam-swinger system and measured angular distributions of emitted neutrons between 0° and 140°. A natural carbon foil of a 2.47 mg/cm^2 thickness was prepared by rolling of graphite for ^{12}C, and a 5.30 mg/cm^2 thick Mylar foil was used for ^{16}O. The carbon contributions were subtracted from the Mylar spectra. A 10 μm thick natural Si single crystal was used for ^{28}Si. Further details of the experimental arrangements have been published elsewhere.[14]

II RESULTS AND DISCUSSION

A The ^{12}C(p,n)^{12}N reaction

A representative neutron energy spectrum for the ^{12}C(p,n)^{12}N reaction obtained at $E_p = 40$ MeV is shown in Fig. 1. In addition to the ground- and first excited states, which are the isobaric analog states in ^{12}C at 15.110 MeV (1^+) and 16.107

MeV (2^+), a prominent peak at E_x = 4.31 MeV in ^{12}N is seen to be excited. We tentatively assign this state to be the analog of the 4^- state at E_x = 19.5 MeV in ^{12}C, which was observed through M4 resonance of the (e,e') experiment[15], from the energy systematics and the angular distribution of the cross sections illustrated in Fig. 2. The DWBA predictions in Figs. 2 and 3 is obtained by the code DWBA-70[16]. A set of effective interactions (M3Y)[17] is employed for the p-n interaction. Pure ($\pi p3/2^4, \nu p3/2^4$) configuration is assumed for the ground state of ^{12}C and ($\pi d5/2p3/2^4, \nu p3/2^3$)$_4-$ for the final state. The calculated angular distribution shape for this state is in good agreement with the measurement, supporting the 4^- assignment.

The cross-section magnitude calculated for the 4^- state with the pure configuration is much larger than the experimental value: σ_{exp}/σ_{th} is found to be 0.21 as tabulated in Table 1. It should be worthwhile to point out that the ratio is in good agreement with that from the (e,e') transition. It has been shown that the tensor force plays the most important role in the analyses of the 135-MeV (p,p') data.[10,18,19] In the present case about a half of the calculated cross section is due to the tensor force. Furthermore, the exchange effect, which is correctly taken into account in the code DWBA-70, is very significant for the prediction of the cross section.

B The ^{16}O(p,n)^{16}F reaction

Many authors have discussed about the stretched 4^- states in A=16 nuclei by the (p,p') experiments[20-22], the π^+ and π^- inelastic scattering[23], the (p,n) reaction at E_p = 35 MeV[13], and $\sigma(\theta)$ and A(θ) measurements for the (p,n) reaction at 134 MeV[12]. Our (p,n) study at E_p = 35 MeV reveals evidence of higher-order reaction processes, which may involve virtual excitation of giant multipole resonances. Indeed, the measured angular distribution of the cross section is not well reproduced in the case of the ^{16}O(p,n)^{16}F reaction as shown in Fig. 2.

C The ^{28}Si(p,n)^{28}P reaction

Figure 3 shows the energy spectrum for the ^{28}Si(p,n)^{28}P reaction at a large laboratory angle of 80°. A sharp prominent peak is observed at E_x = 5.001 MeV. We estimate the width of this state to be 45 keV by quadratically subtracting the contributions of time spread and target thickness from the observed peak width. Comparing the 6^- stretched state in ^{24}Al (see Ref. 11) the width is less than one-half. In Fig. 4, the angular distribution of the emitted neutrons leading to this state is presented. A good fit may confirm the 6^- assignment together with the excitation energy systematics listed in Table 1.

III SUMMARY

We observed systematically 4^- and 6^- stretched states in the daughter nuclei of light N=Z nuclei. As summarized in Table 1, the present results are consistent

with those from (e,e') and (p,p') experiments in spite of the fact that the momentum transfer involved in the present work is much smaller than such intermediate energy reactions. The missing M4 and M6 strengths cannot be attributed to the choice of the effective interactions therefore. It should be emphasized that the excitation energies are also in excellent agreement between the parent and daughter nuclei.

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Table 1

Excitation energies and ratios of σ_{exp}/σ_{th}(DWBA) for the stretched states in light N=Z nuclei obtained from the present study. A comparison for the excitation energies with the (e,e') and (p,p') experiments is also listed.

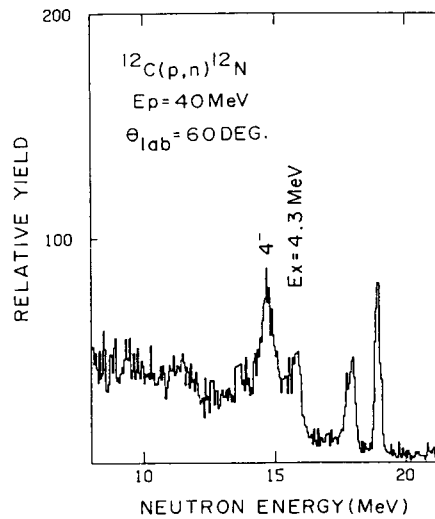| A	(e,e'), (p,p') Final state J^π	E_x(MeV)	(p,n) Final state J^π	E_x(MeV)	E_x in target(MeV)	$\dfrac{\sigma_{exp}}{\sigma_{th}}$
12	^{12}C, 4^-	$19.5^{a)}$	^{12}N, 4^-	4.31 ± 0.08	19.41	0.21
16	^{16}O, 4^-	$18.98^{b)}$	^{16}F, 4^-	6.413 ± 0.020	18.958	0.2-0.3
24	^{24}Mg, 6^-	$15.137^{c)}$	^{24}Al, 6^-	5.545 ± 0.025	15.060	0.25
28	^{28}Si, 6^-	$14.350^{c)}$	^{28}P, 6^-	5.001 ± 0.020	14.311	0.27

a) Ref. 15
b) Ref. 23
c) Ref. 24

Fig. 1. Neutron energy spectrum for the reaction ^{12}C(p,n)^{12}N at θ_{lab} = 60° measured with 40-MeV protons at a neutron flight path of 24.6 m. The ordinate is compensated for the variation of the detector efficiencies with respect to neutron energy. Energy per bin is 50 keV.
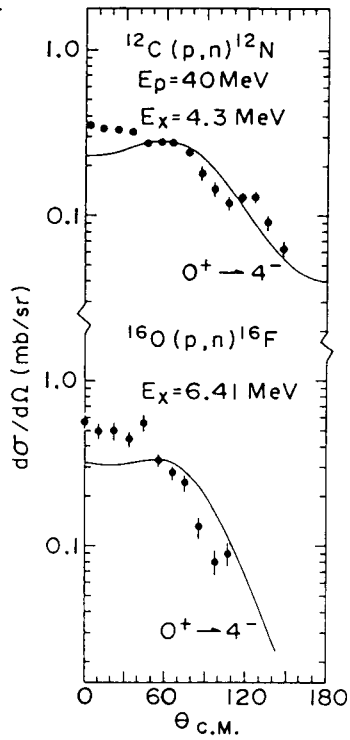
Fig. 2. Differential cross sections for the 4.31-MeV state in ^{12}N and 6.413-MeV state in ^{16}F. The curves are DWBA predictions calculated with the M3Y interaction.
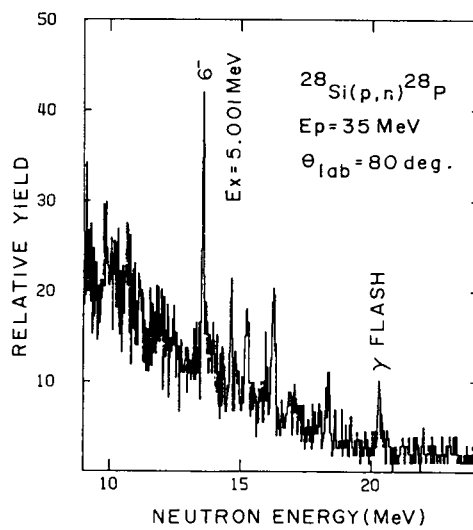

Fig. 3. Same with Fig. 1 but for ^{28}Si(p,n)^{28}P at θ_{lab} = 80° measured with 35-MeV protons.

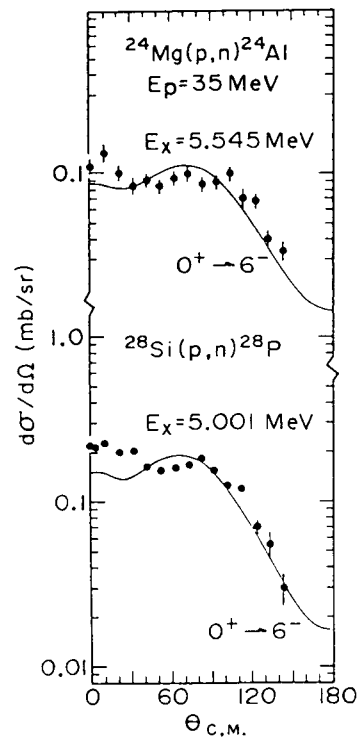Fig. 4. Same with Fig. 2 but for the 5.45-MeV state in ^{24}Al and 5.001-MeV state in ^{28}P, and energy per bin is 25 keV.