I. 6 OHω Stretched States Observed in the (p,n) Reaction on sd-Shell Nuclei

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Study of an isovector stretched magnetic transition is of particular significance, since the number of one-particle one-hole excitation is severely restricted, and since such transitions may provide a good place to probe spin-isospin properties of nuclei, and to study the isovector part of tensor interaction in the effective N-N interactions at high-q and in a large angular momentum transfer. Stretched particle-hole states have been so far investigated through backward angle electron scattering, pion inelastic scattering, nucleon scattering and charge-exchange reaction etc.

Stretched high spin particle-hole state was firstly found by Zarek et al.1) in the backward angle electron scattering on $^{24}$Mg with momentum transfers up to $\sim$800 MeV/c. They located $\hbar\omega$-jump $6^{-}$, $T = 1$ resonance at $E_x = 15.130$ MeV in $^{24}$Mg, while the same state was observed by Adames et al.2) through proton inelastic scattering at $E_p = 135$ MeV. A systematic investigation has been reported3) for the low-energy (p,n) reactions on $^{12}$C, $^{16}$O, $^{24}$Mg and $^{28}$Si, where [f$^5_2$, p$^3_2$]$^{-1}_4$ and [f$^7_2$, v$^-_5$]$^{-1}_6$ - $\hbar\omega$ stretched states were observed in p- and sd-shell nuclei, respectively. In intermediate (p,n) work, Anderson and his collaborators have observed $\hbar\omega$ stretched states in the $^{28}$Si(p,n) and $^{40}$Ca(p,n) reactions. One of the striking features found in the studies for the $\hbar\omega$ stretched state is their considerably large quenching. This seems even to be independent of the choice of the probe to be investigated. Indeed, Petrovich and Lindgren4) have suggested that the extracted values of $S^2$ (a measure of the quenching) for the isovector $\hbar\omega$ transition are typically 38 % of extreme single particle model estimation by discussing (e,e'), (p,p'), (p,n), ($\pi^+$,$\pi^-$) and ($\pi^-$,$\pi^-$) scattering.

Meanwhile, $\Omega\hbar\omega$ stretched states, which lies at rather low excitation energy, have been so far studied by the (p,n) reaction. Anderson et al.5) have reported $\Omega\hbar\omega$ 7+, 7+, 9+ and 13+ stretched states by the (p,n) reactions on $^{48}$Ca, $^{54}$Fe, $^{88}$Sr and $^{208}$Pb, respectively, at 134 MeV. Contrary to the cases of $\hbar\omega$ negative parity stretched states, they have reduced larger $S^2$ values ranging 0.60 (for $^{48}$Ca) through 0.96 ($^{208}$Pb) in $\Omega\hbar\omega$ cases. In this note we report observation of the $\Omega\hbar\omega$ stretched state in p- and sd-shell
nuclei by means of the low-energy \((p,n)\) reaction. Though interpretation of
the data in terms of the distorted-wave impulse approximation (DWIA) is
expected to be reliable at reasonably high incident energy, the low-energy
experiments are also attractive because of the better energy resolution
achieved. This seems indeed true for investigation of the presently discussed
\(0^+\) stretched state which appear in a lower excitation energy region with
separation of \(\approx 100\) keV from near-by lying states. Care must be exercised, of
course, in analyzing the low-energy \((p,n)\) data with DWBA theory as discussed
in details positively by Ohnuma et al.6)

In Figs. 1 and 2, shown are the large-angle neutron sample spectra taken
for the \((p,n)\) reactions on \(^{22}\text{Ne}\) and \(^{26}\text{Mg}\). The \(5^+\) stretched states are clearly
resolved for both cases. The experiments were performed with use of a 35 MeV
proton beam from the AVF cyclotron and the time-of-flight facilities\(^7\) at the
Cyclotron and Radioisotope Center, Tohoku University. A self-supporting \(^{26}\text{Mg}\)
foil of 2.6 mg/cm\(^2\) thickness and enriched to 99.9\% in \(^{26}\text{Mg}\) for the
\(^{26}\text{Mg}(p,n)^{26}\text{Al}\) reaction, while a gas cell with metallic calcium foil windows
and filled with neon gas, the effective thickness for which was 1.0 mg/cm\(^2\) and
enriched to 99.9\% in \(^{22}\text{Ne}\), was used for the \(^{22}\text{Ne}(p,n)^{22}\text{Na}\) reaction. The
overall time resolution for the \(\gamma\)-flash was 0.9 ns corresponding to 100 keV
for the most energetic neutron over a flight path of 44 m. The errors in the
absolute cross section are estimated to be less than 15\%.

Figure 3 shows angular distributions for the two \(0^+-5^+\) transitions in
the \((p,n)\) reactions on \(^{22}\text{Ne}\) and \(^{26}\text{Mg}\). The curves in the figure are DWBA
predictions described below. No scaling of our calculations has been made to
optimize comparisons. DWBA calculations were made with the code DWBA74.\(^8\)
Optical-potential parameters for protons and neutrons were taken from Ref. 9.
Choice of optical potential parameters may introduce ambiguities of \(\sim 20\%\) for
the predicted cross sections, but not the relative ones as reported in Ref. 6.
We have tested this by fitting absolutely the \(0^+-0^+\) and \(0^+-2^+\) analog
transitions, which have been studied in similar conditions. A set of
effective interactions of Bertsch et al.\(^10\) (M3Y) was used in the
calculations. More specifically, we used a combination of those based on the
Reid soft core central and LS odd forces and the Elliot LS even and tensor
force.\(^10\) Transition amplitudes have been obtained from the one-body
transition densities in the 0s-0p-1s0d model space calculated by Brown et
al.\(^11\) Recently, a stringent test for the shell model has been successfully
carried out\(^12\) by analyzing the low-energy \((p,n)\) data for various kinds of
transitions in sd-shell nuclei.

The present DWBA calculation reproduces the backward angle cross sections
very well, particularly with the normalization factor of unity. This leads to
a speculation that the presently applied effective interaction, especially its
tensor part is reasonable even in large transfer momentum region \((q \approx 1.0
\text{through 2.0 fm}^{-1})\) as in the case of the low-\(q\) \((\approx 0.5 \text{ fm}^{-1})\) region reported by
Orihara et al.\(^14\) with \(\Delta q = 0^-\) transition, in addition to the optical
potential parameters and transition amplitudes which have been checked by another way as mentioned earlier. Discrepancy between the theory and experiment at forward angle cross sections is remarkable. This problem seems to be a general feature of the stretched transition at low energies. In the $^{28}$Si(p,n)$^{28}$P reaction leading to the 6$^{-}$ state$^{13}$, the situation is indeed same. For l=0 high-lying transition, there may be unresolved contaminations from low-L transitions. For the present 0=0 transition, however, the peak is isolated one as seen in Figs. 1 and 2.

In summary, a number of 0=0 stretched states in p- and sd-shell nuclei were observed by the high-resolution (p,n) work at low-energy as isolated peaks. Their cross section magnitudes have been well explained by the theory. The inconsistency at forward angles is still open problem.

References

6) Ohnuma H. et al., to be published in Nucl. Phys.
Fig. 1. Large angle neutron energy spectra for the (p,n) reactions on $^{27}$Ne and $^{26}$Mg. Ordinates are compensated by neutron detection efficiencies.
Fig. 2. Angular distributions of neutrons leading to the $0^+\omega$, $[\pi d_{5/2}$, $v_{5/2}^{-1}]_5^-$ stretched states in $^{22}\text{Na}$ and $^{26}\text{Al}$. Curves in the figure are DWBA predictions described in text.