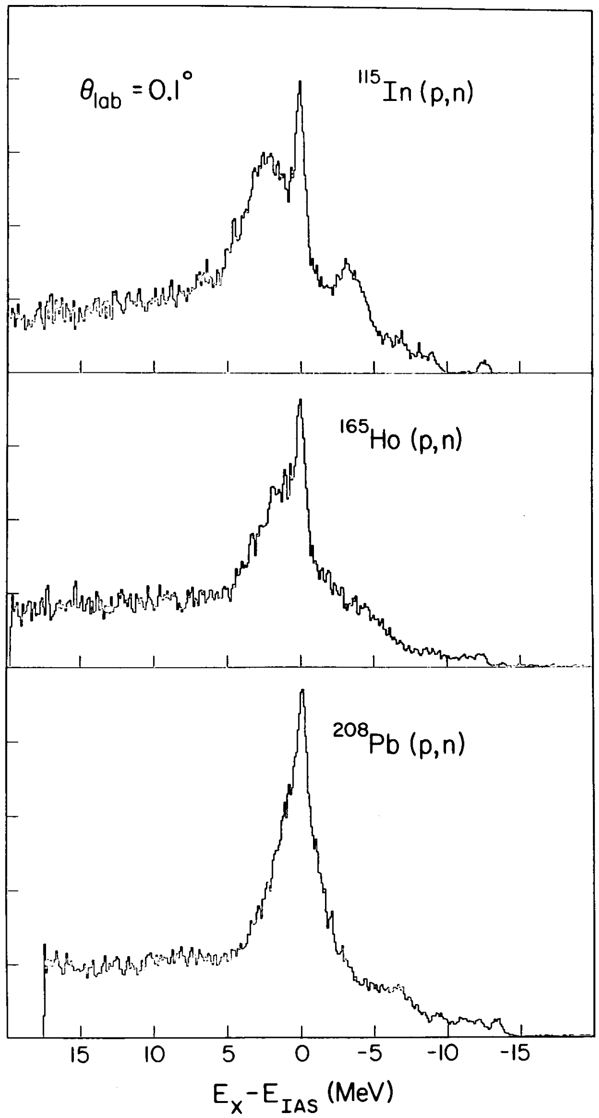


Figure 2. $^{115}$In(p,n), $^{165}$Ho(p,n), and $^{208}$Pb(p,n) spectra obtained at $\theta_{lab}$ = 0°, $E_p$ = 160 MeV. The IAS peaks are positioned at $E_x - E_{IAS}$ = 0.


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## HIGH-SPIN "STRETCHED" STATES EXCITED IN (p,n) REACTIONS


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The excitation of unnatural parity states of high angular momentum is an area of strong current interest[1-6] in medium-energy physics. Isovector excitations are especially interesting because of their strong sensitivity to the isovector-tensor part of the nucleon-nucleon force. In the momentum-transfer region between 1 and 2 $fm^{-1}$, the isovector-tensor term dominates[1)] for unnatural parity transitions ($\Delta J \neq \Delta L$). Interest has been focused[7,8)] on high-spin states with a major configuration of the "stretched" particle-hole type because the number of terms contributing to the amplitude for (p,n) reactions[7)] or inelastic scattering[8)] is severely reduced. A stretched particle-hole configuration is one where the particle and hole are both in stretched subshells ($j = \ell + 1/2$), and are coupled to the maximum possible angular momentum $\ell_p + \ell_h + 1$.

Previous theoretical and experimental work on the excitation of particle-hole stretched states in inelastic scattering and (p,n) reactions involved major configurations with the particle in the next major shell above the hole; accordingly, we refer to such states as "1 $\hbar\omega$" stretched states. They have odd parity. Lindgren et al.[2)] give a partial summary of this work. There is another class of unnatural parity stretched states that can be excited by (p,n) reactions on targets with $N > Z$. In the major configuration for these states, the proton particle and the neutron hole have the same quantum numbers n, $\ell$, and j; accordingly, we refer to these states as "0 $\hbar\omega$" stretched states. They have even parity. Such states are known from low-energy work on ($^3$He,t) reactions where large $\ell$-transfers are reached easily. A 1 $\hbar\omega$ stretched state has a unique particle-hole configuration in a basis which includes 0,1, and 2 $\hbar\omega$ excitations; a 0 $\hbar\omega$ stretched state has a unique particle-hole configuration in a basis which includes 0 and 1 $\hbar\omega$ excitations. We note that the Pauli exclusion principle prohibits the excitation of 0 $\hbar\omega$ stretched states by (p,n) reactions on self-conjugate targets or by inelastic scattering on any target.

In the $^{48}$Ca(p,n)$^{48}$Sc reaction at 160 MeV, we observed the strong excitation of a 0 h$\omega$ stretched state, namely, the $J^\pi = 7^+$ state at 1.096 MeV with a $(\pi f_{7/2}, \nu f^{-1}_{7/2})$ proton-particle neutron-hole major configuration. Neutron energy and angular distributions were measured by the time-of-flight technique with the beam swinger facility with two detector stations. We achieved an overall time resolution of about 0.50 ns including the beam burst width, the intrinsic resolution of the detectors, the energy spread from the 29.3 ± 0.5 mg/cm$^2$ target thickness and the beam energy spread. Typical energy resolutions, therefore, were 450 keV in the first detector station at 68.0 m and 400 keV in the second detector station at 76.3 m.

Fig. 1 shows energy spectra for the $^{48}$Ca(p,n)$^{48}$Sc reaction at laboratory scattering angles of 24.0°, 30.5°, 35.8°, and 42.2°. The energy scale is expressed in terms of the excitation energy in $^{48}$Sc. In the 24° to 42° region, the typical momentum transfers range from 1.2 to 2.2 $fm^{-1}$, which is the momentum transfer region where the tensor force is expected to excite high-spin stretched states. In the region of excitation energy between 10 and 25 MeV, where 1 $\hbar\omega$ stretched states with either a $(\pi g_{9/2}, \nu f^{-1}_{7/2})8^-$ or $(\pi f_{7/2}, \nu d^{-1}_{5/2})6^-$ configuration would be expected to occur, we observed no sharp peaks in the spectra.[10)] We set an upper limit of 60 μb/sr for the excitation of 1 $\hbar\omega$ stretched states in $^{48}$Sc. Adams et al.[4)] reported the absence of 1 $\hbar\omega$ stretched states in the $^{32}$S and $^{40}$Ca(p,p') reactions at 135 MeV.

The only states excited strongly in the spectra of Fig. 1 are the $6^+$ ground state and the $7^+$ state at 1.096 MeV. These states are members of the low-lying particle-hole multiplet with a $(\pi f_{7/2}, \nu f^{-1}_{7/2})$ configuration.[9)]

We note that the $7^+$ ($E_x$ = 1.096 MeV) member of the

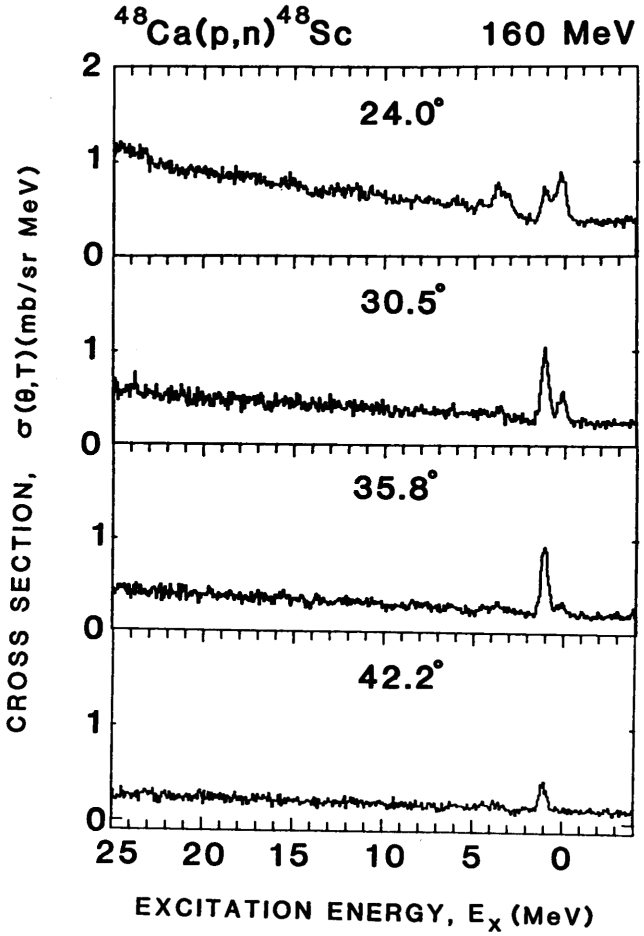


Figure 1. Neutron energy spectra at laboratory angles of 24.0°, 30.5°, 35.8°, and 42.2° for the $^{48}$Ca(p,n)$^{48}$Sc reaction at 160 MeV.

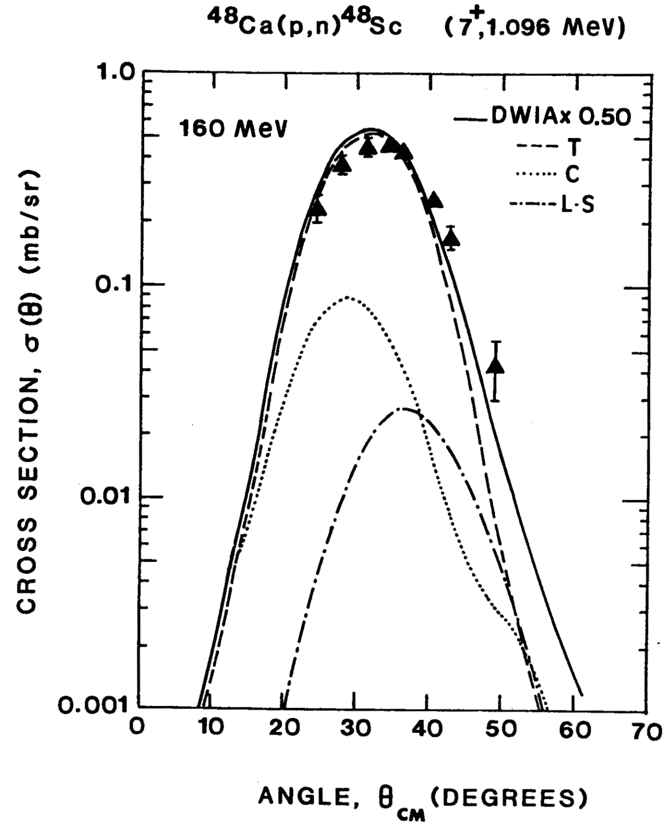


Figure 2. Angular distribution of the $^{48}$Ca(p,n)$^{48}$Sc($7^+$, 1.096 MeV) reaction at 160 MeV. Shown also are DWIA calculations made with the computer code DWBA70 with $^{40}$Ca optical model parameters and $1f_{7/2}$ harmonic oscillator wave-functions. The dotted, dashed, and dash-dotted curves represent contributions from the isovector central (C), tensor (T), and spin-orbit (L·S) terms, respectively, of the effective interaction. The solid curve represents the coherent sum of these three isovector terms.

$(\pi f_{7/2}, \nu f^{-1}_{7/2})$ multiplet is a 0 ħω stretched state. figure 2 shows the angular distribution of the cross section for the $7^+$($E_x$=1.096 MeV) state. Also shown is a DWIA calculation made with the computer code DWBA70[10] with the effective interaction of Love,[1] $^{40}$Ca optical-model parameters from Schwandt et al.,[11] and $1f_{7/2}$ harmonic-oscillator wave functions. The DWIA calculation was multiplied by 0.50. Also shown are the results of calculations with each one of the three isovector terms (viz., central, spin-orbit, and tensor) of the effective interaction which can contribute to unnatural parity transitions. From Fig. 2, it is clear that the isovector-tensor term in the effective interaction is primarily responsible for the transition to the $7^+$ stretched state.

The normalization factor of 0.50 is significantly larger than those reported by Lindgren et al.[2] for (p,p') transitions to states which are strictly of the stretched 1 ħω type except for the $14^-$state of $^{208}$Pb. Although comparison of our data for the $7^+$ 0 ħω stretched state with inelastic electron scattering data is not possible because 0 ħω stretched states cannot be excited in inelastic scattering, the relatively large normalization factor for the $7^+$ state is encouraging since $^{48}$Ca is known to be a reasonably good shell-model nucleus.

In conclusion, we observed strong excitation of a $0\hbar\omega$ stretched state in the $^{48}Ca(p,n)^{48}Sc$ reaction at 160 MeV, namely, the $7^+$ state at 1.096 MeV, with a $(\pi f_{7/2}, \nu f^{-1}_{7/2})$ major configuration; however, we found no evidence for $1\hbar\omega$ stretched states based on $(\pi g_{9/2}, \nu f^{-1}_{7/2})8^-$ or $(\pi f_{7/2}, \nu d^{-1}_{5/2})6^-$ configurations. The excitation of stretched states of the $0\hbar\omega$ type should prove to be a useful tool for studying the isovector-tensor term of the effective nucleon-nucleon interaction.


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## MEASUREMENT OF THE 1/E DEPENDENCE OF THE $^{7}Li(p,n)^{7}Be$ TOTAL REACTION CROSS SECTION


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The excitation function, $\sigma(E)$, of the $^{7}Li(p,n)^{7}Be$ reaction was measured in the intermediate energy range of 60-199 MeV using activation techniques and $\gamma$-ray spectroscopy. This method has been used to measure the total cross section at energies of 25-44 MeV by Shery et al.[1] and at 120 MeV by Goulding et al.[2] to calibrate large volume neutron detectors. Details of the experimental procedure can be found in the IUCF 1979 annual report.[3] A summary of the results is given in Table 1. The total errors estimated for these measurements range from 8 to 14%.

The measured[1,4] excitation function, $\sigma(E)$, of the $^{7}Li(p,n)^{7}Be$ total reaction cross ssection is observed to vary inversely with the incident proton energy, E, from 25 to 200 MeV. A theoretical analysis, assuming the PWIA with an energy-independent, very-short-range interaction, using harmonic oscillator wave functions and neglecting exchange effects, yields a 1/E dependence for the summed inelastic scattering differential cross section to a particular state. This result implies that $\sigma(E) = 725.3\ (1/E) - 0.295$ with $\sigma$ in millibarns, E in MeV and a determinant coefficient of 0.998.

Further, it implies that the interaction strength