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POLARIZED PROTON RADIATIVE CAPTURE STUDIES OF GIANT RESONANCES

MASTER

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ABSTRACT

Several interesting E1, M1 and E2 resonance studies in $(\vec{p},\gamma)$ reactions are discussed. These include a unique determination of E1 amplitudes in the $^{12}C(\vec{p},\gamma_0)^{13}N$ reaction, E2 strength in the $^{15}N(\vec{p},\gamma_0)^{16}O$ reaction, M1 decays to the ground states and to the excited 0^+ states of the doubly magic ^{16}O and ^{40}Ca nuclei, and the M1 γ-decay of the stretched 4^-, T=1 particle-hole state in ^{16}O.

INTRODUCTION

Radiative proton capture is a powerful tool for investigations of electromagnetic decays from nuclear resonances in the continuum. Measurements of polarized proton capture can in many cases provide the necessary information to determine resonance multipolarities E1, E2 or M1. For isolated resonances, it is well-known that experiments which measure only the angular dependence of the γ-ray intensity cannot determine the parity of the radiation (M*L* or E*L*). However, continuum resonances are never completely isolated, and a sensitivity to the multipole character, including the parity of the radiation, comes about through resonance-background interference in the angular distribution of the capture radiation, along with some knowledge of the background character (usually predominantly E1).

For most (p,γ) reactions, on the average, E1 radiation is dominant and E2 radiation is present with an intensity 1-2 orders of magnitude weaker than E1. M1 radiation appears to be weakest, although strong M1 resonances may occur at low ($E_p \lesssim 10$ MeV) energies. The pioneering $(\vec{p},\gamma)$ studies of E1 and E2 radiation were performed at Stanford University[1,2] and were described by H.F. Glavish at the previous polarization conference.[3] Since then we have learned much more about E2 strength, which I will discuss briefly. The sensitivity of $(\vec{p},\gamma)$ to the identification of M1 resonances, discovered at Seattle, has led to several interesting studies of M1 resonances. I will mainly discuss these studies, since both the techniques and the physics of these measurements are interesting and different from the earlier $(\vec{p},\gamma)$ studies.

TECHNIQUE

The cross section $\sigma(E,\theta)$ and analyzing power $A(E,\theta)$ for the capture of polarized particles may be defined in the usual manner as

$$\sigma(E,\theta) = [\sigma\uparrow(E,\theta) + \sigma\downarrow(E,\theta)]/2 \qquad (1)$$

and

$$\sigma(E,\theta)A(E,\theta) = [\sigma\uparrow(E,\theta) - \sigma\downarrow(E,\theta)]/2P \qquad (2)$$

where $\sigma\uparrow$ and $\sigma\downarrow$ are the cross sections for an incident beam of energy E and vector polarization of magnitude P oriented along ($\uparrow$) or against ($\downarrow$) the normal $\hat{n} = \vec{K}_{in} \times \vec{K}_{out}$ to the reaction plane.

The dependence on γ-ray emission angle θ may be expanded as

$$\sigma(E,\theta) = \sum_{K=0}^{2L_{max}} A_K(E)Q_K P_K(\cos\theta) \qquad (3)$$

and

$$\sigma(E,\theta)A(E,\theta) = \sum_{K=1}^{2L_{max}} B_K(E)Q_K P_K^1(\cos\theta) \qquad (4)$$

Here $\sigma_{total} = 4\pi A_o$, L_{max} is the maximum multipole which contributes ($L_{max} = 2$ for dipole + quadrupole) and the Q_K are the usual angular attenuation factors. It is often convenient to define fractional Legendre coefficients $a_K = A_K/A_o$, $b_K = B_K/A_o$. For the capture of polarized spin-1/2 particles on unpolarized targets, with only the γ-ray intensity (at a given energy and angle) observed in the outgoing channel, the above equations completely specify the (parity-allowed) capture process.

The usual angular momentum coupling rules tell us that interference between opposite (same) parity radiations contributes to the odd (even) coefficients so that E1-M1 interference contributes to A_1 and B_1, E1-E2 to A_1, B_1, A_3, B_3, etc. The exact relations may be written down as

$$A_k = \sum_{tt'} D_{tt'k} \, \mathrm{Re}\, T_t T_{t'}^* , \qquad (5)$$

and

$$B_k = \sum_{tt'} f_k(tt') D_{tt'k} \, \mathrm{Im}\, T_t T_{t'}^* , \qquad (6)$$

where T_t, $T_{t'}$ are the reaction amplitudes for different channels t and t', the $D_{tt'k}$ are angular momentum coupling factors and

$$f_k(tt') = [j'(j'+1) + \ell(\ell+1) - j(j+1) - \ell'(\ell'+1)]/2k(k+1) \qquad (7)$$

where ℓ, j, ℓ', j' are the interfering orbital and total angular momenta for the incident nucleon.

For the simplest spin sequence ($J_{target} = 1/2$, $J_{residual} = 0$ or vice versa), only 2 complex reaction amplitudes contribute for each multipole. For cases of this sort involving $1p_{1/2}$-shell targets, the amplitudes are

$$E1 : s_{1/2}e^{i\phi_{s_{1/2}}} , d_{3/2}e^{i\phi_{d_{3/2}}}$$

$$E2 : p_{3/2}e^{i\phi_{p_{3/2}}} , f_{5/2}e^{i\phi_{f_{5/2}}}$$

$$M1 : p_{1/2}e^{i\phi_{p_{1/2}}} , p'_{3/2}e^{i\phi'_{p_{3/2}}}$$

If only electric multipoles contribute at a given energy, the problem is overdetermined (e.g., 9 independent A_K, B_K versus 7 amplitude parameters for E1 + E2) whereas if magnetic multipoles contribute, the problem is underdetermined (E1 + E2 + M1 requires 11 amplitude parameters). However, as we show below, one may use $(\vec{p},\gamma)$ to uniquely determine E1 amplitudes, identify the multipolarity E1, E2 or M1 of resonances, and provide E2 cross sections for broadly distributed strength in the continuum.

E1 CAPTURE AMPLITUDES

For the simple spin sequences described above, only 2 complex E1 amplitudes contribute, and $(\vec{p},\gamma)$ angular distribution measurements restrict the E1 amplitudes to 2 possible solutions. This 2-fold ambiguity is inherent, resulting from the quadratic nature of the equations relating the amplitudes to the data. A typical example in light nuclei is the $^{12}C(p,\gamma_0)^{13}N$ reaction,[4,5] illustrated in Fig. 1. The GDR region extends from $E_p \sim 8$-30 MeV with $(\vec{p},\gamma_0)$ angular distribution results[4] for E_p = 10-17 MeV. Only incoming s- and d-wave amplitudes (with j = 1/2 and 3/2, respectively) may contribute to E1 capture, and Fig. 1 shows that one of the 2 solutions is predominantly d-wave ($d_>$) and the other predominantly s-wave ($s_>$).

Similar $d_>$ and $s_>$ solutions are obtained for other capture reactions such as $^{14}C(\vec{p},\gamma_0)$[6] and $^{15}N(\vec{p},\gamma_0)$[2,7,8] (Fig. 2), indicating that one is observing a general feature of the GDR build on $1p_{1/2}$-shell nuclei. The $d_>$ solution is expected on theoretical grounds—virtually all models of radiative capture through the GDR, such as the doorway-state[10] or the direct-semidirect (DSD)[9,4] models, predict that d-waves should dominate, with results in reasonable agreement with the experimental data if the $d_>$ solution is the correct (physical) one.

However, one does not need a detailed calculation to understand why d-wave capture is expected to dominate. Relative to the ^{13}N ground-state, the configurations in the GDR which contribute to pro-

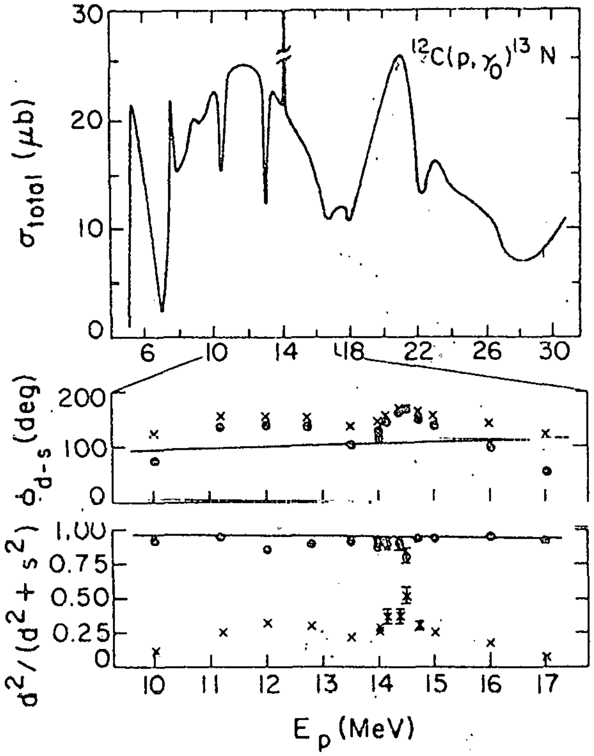

Fig. 1. Upper part: σ_{total} for $^{12}C(\vec{p},\gamma_0)$ (refs. 4-5). Lower part: The d-s phase difference and the relative d-wave intensity for E_p = 10-17 MeV (ref. 4 plus ref. 12 for 14 < E_p < 15 MeV). The points and crosses correspond to the $d_>$ and $s_>$ solutions, respectively. The solid lines are DSD calculations described in ref. 4.

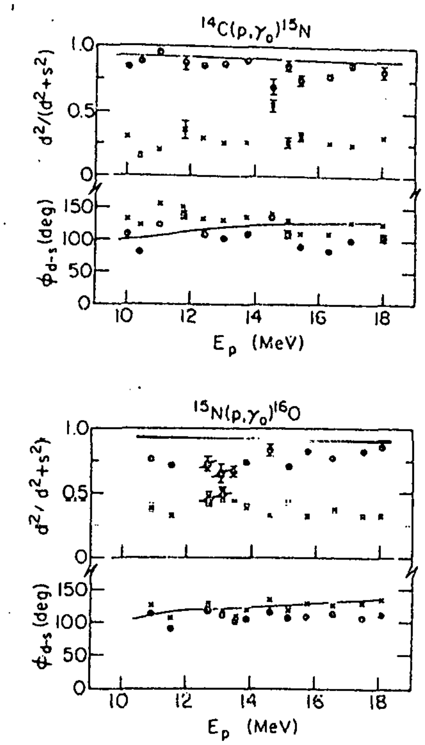

Fig. 2. The relative d-wave intensity and the d-s phase difference for $^{14}C(\vec{p},\gamma_0)$ (ref. 6) and $^{15}N(\vec{p},\gamma_0)$ (refs. 7,9). The solid curves are DSD model predictions (see ref. 9).

ton capture are $(1d)^1\,(1p_{1/2})^{-1}$ and $(2s)^1\,(1p_{1/2})^{-1}$, and the schematic model predicts the amplitudes for these configurations should be in the ratio of the E1 matrix elements connecting these configurations to the ground state. Since $\langle 1d|E1|1p_{1/2}\rangle \gg \langle 2s|E1|1p_{1/2}\rangle$ (the first matrix element has a good radial overlap while the second involves a node change resulting in radial cancellations), this predicts d-wave capture should dominate. This is a special application of a more general rule discussed many years ago by Wilkinson[11] that E1 photoabsorption in the GDR should be dominated by nucleon excitations of the form $n\ell \rightarrow n'\ell'$ where $n\ell$ is an occupied shell model orbital and $n'\ell'$ an unoccupied orbital with $n' = n$, $\ell' = \ell+1$.

At Seattle we recently determined[12] that the $d_>$ solution is the physically correct one by making the first unique E1 amplitude determination in radiative capture. We did this by studying the interference between the lowest T = 3/2 M1(E2) resonance at E_p = 14.23 MeV and the E1 background in the $^{12}C(\vec{p},\gamma_0)$ reaction. The basic idea is to use interference with a known resonance to determine unknown properties of the background.

The dominant M1-E1 interference effects should appear in the A_1 and B_1 coefficients; hence we measured excitation curves at 90° with a polarized beam and 55° and 125° with an unpolarized beam. The results are shown in Fig. 3 for

$$[\sigma(55°) + \sigma(125°)]/2 = A_0 - 0.39\,A_4 \approx \sigma_{total}/4\pi$$

$$\sigma A(90°) = B_1 - 1.53\,B_3$$

$$[\sigma(55°) - \sigma(125°)]/2 = 0.57\,A_1 - 0.39\,A_3$$

The experimental data for the latter 2 quantities clearly show pronounced interference effects.

We calculated resonance curves using the known T = 3/2 resonance parameters of ref. 13 and background E1 and E2 amplitudes determined from off-resonance angular distributions. For the interference shapes in $\sigma(90°)A(90°)$ and $\sigma(55°) - \sigma(125°)$, the only free parameter was the phase of the T = 3/2 resonance relative to the E1 background. The results clearly select the $d_>$ solution as the physically correct one.

These measurements also provide restrictions on the E2 contributions to this reaction.[12] In principle, more extensive measurements of this sort could uniquely determine the E2 amplitudes. Also this technique could be applied to other nuclei where known multipolarity resonances occur at sufficiently high excitation energy to be used for unique determinations of giant resonance amplitudes and phases.

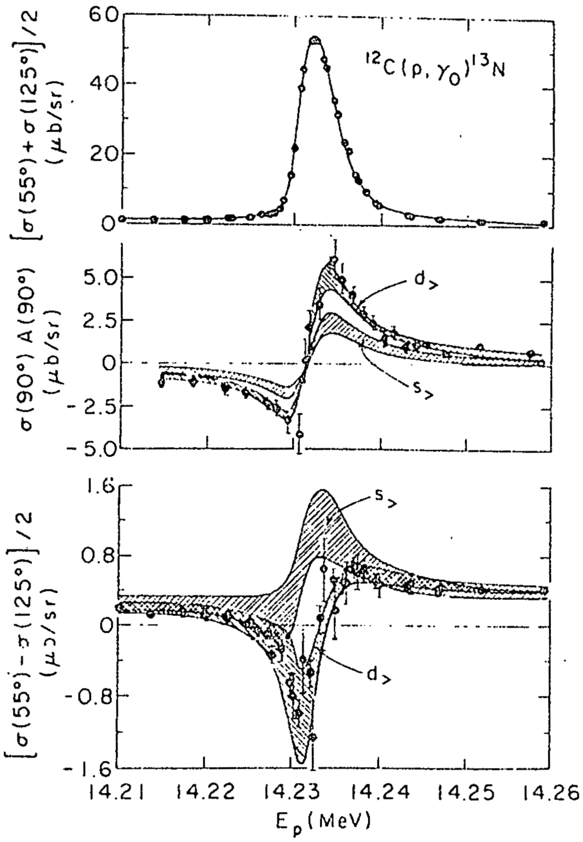

Fig. 3. Excitation curves taken near the lowest T = 3/2 resonance in $^{12}C(p,\gamma_0)^{13}N$ (ref. 12). The solid curve in the top part is a calculated fit. The bands in the lower 2 parts represent the spread of calculated curves for the $d_>$ and $s_>$ solutions consistent with off-resonance angular distributions.

E2 STRENGTH

Effects of E2 radiation are apparent in most (p,γ) studies in and above the GDR region. Direct E2 capture contributes strongly in the GDR region, and in many cases E1 capture plus direct E2 capture accounts for the observed cross sections and angular distributions; in many other cases it is difficult to discern whether or not additional (collective) E2 strength is present (see refs. 4, 6, 8, 14, 15). $(\vec{n},\gamma)$ studies, as discussed by H.R. Weller at this conference, should be free of direct E2 effects, but are quite difficult experimentally. Decay studies of the isoscalar giant quadrupole resonance (GQR) show[16] that in most cases p_0 is a weak decay channel, in agreement with direct-semidirect calculations.[6] This is due to the large spreading width and, in light nuclei, non-statistical decay to the α-channel. Nevertheless, (p,γ) E2 strength remains interesting because of the possibility of collective isovector contributions, about which little is known. There remain a few cases where $(\vec{p},\gamma)$ studies seem to indicate a significant excess of E2 strength over direct capture.

One such case is $^{15}N(\vec{p},\gamma_0)^{16}O$. The E2 cross sections deduced from $^{15}N(\vec{p},\gamma_0)^{16}O$ measurements at Seattle are shown in Fig. 4 for E_p = 1.4 to 18.0 MeV (E_x = 13.4 to 29 MeV). The data include a reanalysis of the work of Bussoletti et al.,[7] plus new results[17] mainly at the lower energies. Here we show results only at energies where the data are consistent with no M1 radiation (see the following section). The region below $E_x \sim 20$ MeV is made up of a number of small resonances, where one needs to perform a resonance analysis of the

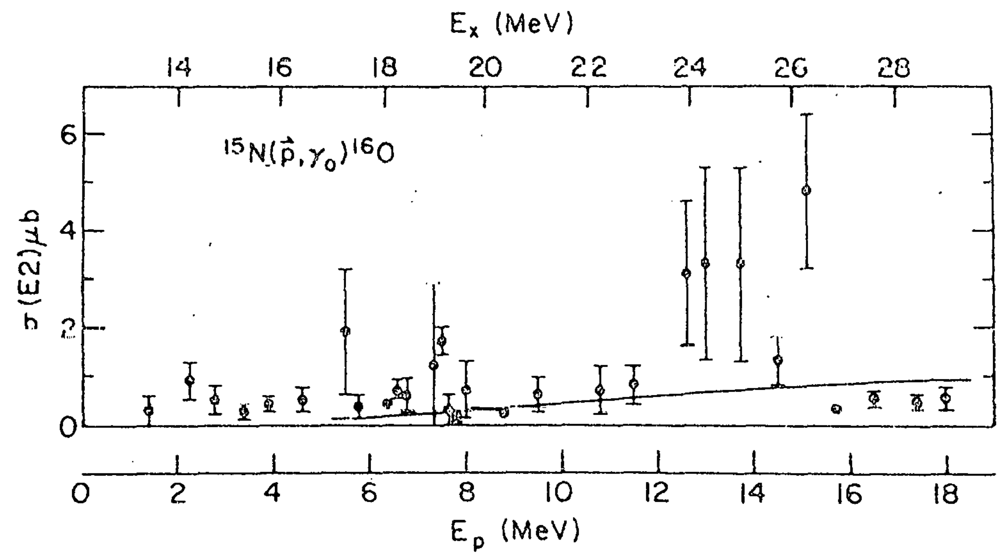

Fig. 4. E2 cross sections for the $^{15}N(\vec{p},\gamma_0)^{16}O$ reactions (refs. 7, 17). The solid line represents calculated direct E2 capture.

angular distribution coefficients in order to understand the strength (this is in progress[17]).

Above E_x = 20 MeV, the only region of possibly significant structure is for E_x = 23-27 MeV, where the present data indicate a strength of roughly 5-10% of the isoscalar E2 energy weighted sum rule (EWSR)[18] in excess of a smooth "background" estimated from the lower points in this region. These data show less evidence for a "GQR" than do previous Stanford data.[2,19] For E_x = 17.9-27.3 MeV where $(\alpha,\alpha' p_0)$ coincidence decay studies[20] show 9% of the EWSR we find in (p,γ_0) 12-22% of the EWSR (calculated direct E2 capture accounts for ∿6% of the EWSR). Thus the integrated E2 strength seen in this region in $(\alpha,\alpha' p_0)$ and (p,γ_0) may be compatible when one accounts for coherent direct capture, without the need to invoke the presence of significant isovector (IV) E2 strength. For E_x = 13.4 to 29 MeV (p,γ_0) shows 20-30% of the EWSR, with direct capture accounting for ∿11% of the EWSR.

M1 DECAYS TO THE GROUND AND THE FIRST EXCITED 0^+ STATES OF ^{16}O

Until recently very little was known about ground-state M1 decays in doubly magic light nuclei. Such decays were generally expected to be weak, since the doubly magic closed shell component of the ground state wavefunction cannot contribute.

Recently we explored this phenomenon at Seattle, with the discovery that M1 excitations can be uniquely identified in radiative capture.[9,21] This was done in the region of semi-isolated resonances below the GDR in the $^{15}N(\vec{p},\gamma_0)^{16}O$ reaction, as illustrated in Fig. 5. Pronounced structure in $A(90°)$ or a_1, which can be non-zero only due to interfering radiations of opposite parity, indicate possible M1 or E2 resonances interfering with the E1 background. The M1 assignments come from fits to detailed angular distributions assuming a model-independent parameterization in terms of E1 and E2 reaction amplitudes. The χ^2 for these angular distribution fits is also shown in Fig. 5. Strong deviations from acceptable values ($\chi^2 \lesssim 2$) indicate areas of concentrated M1 strength. Analysis of the a_i and b_i near these energies shows that the prominent resonances at 16.22 and 17.14 MeV are M1, with a third M1 resonance near 18.8 MeV which in the cross section is unresolved from a neighboring E1 resonance.

These M1 resonances in ^{16}O correspond to a total ground-state M1 strength $B(M1)\downarrow \gtrsim 0.24\ \mu_0^2$. This is quite sizable compared to a non-closed shell A = 4n nucleus such as $^{12}C(B(M1)\downarrow = 0.93\ \mu_0^2)$. The observed M1 decays stem from the ground-state correlations (primarily 2 particle-2 hole) and are in reasonable accord with recent shell model calculations by Arima and Strottman.[22] Between 16 and 20 MeV several M1 states are predicted, with a total strength of 0.27 μ_0^2, which is quite comparable to experiment. At higher energies up to 29 MeV an additional strength of 0.6 μ_0^2 is predicted to be fragmented over a number of levels. The ground-state wavefunction generated in this calculation has a 2p-2h intensity of 17%.

The experimental search for ground state M1 strength predicted at higher energies in ^{16}O represents an intriguing experimental challenge. We have measured A(90°) in fine (100 keV) energy steps from E_p = 9-16 MeV in the $^{15}N(p,\gamma_0)^{16}O$ reaction, and we find no pronounced structure.[17] Additional angular distributions in this region show no significant evidence for M1 strength. However, M1 resonances in this energy region may be either too broad or have too weak a proton formation probability Γ_p/Γ to be observed in $(\vec{p},\gamma_0)$. At lower energies, we find no evidence ($\Gamma_{\gamma_0} < 1$ ev) for a previously reported[23] M1 (p,γ) resonance, in agreement with an earlier electron scattering experiment.[24]

The utility of $(\vec{p},\gamma)$ for discovering M1 transitions has so far been demonstrated only in the one case discussed above. In the future it will be interesting to extend this technique to other nuclei, and to see if M1 resonances can be identified in reactions which do not have the simplest spin sequences (see the discussion below).

More recently we have measured γ-decay branches from the 16.22 and 17.14 MeV 1^+, T = 1 states to the 0_2^+ (6.05 MeV) final state (see Fig. 6) for which we find[25] preliminary values of $B(M1, 1^+ \to 0_2^+)/B(M1, 1^+ \to 0_1^+) = 0.45 \pm 0.03$ and 0.55 ± 0.04, respectively (the strength of these decays rules out a significant contribution from an unresolved M2/E3 branch to the 3^- (6.13 MeV) level). These relatively streong M1 decays should provide

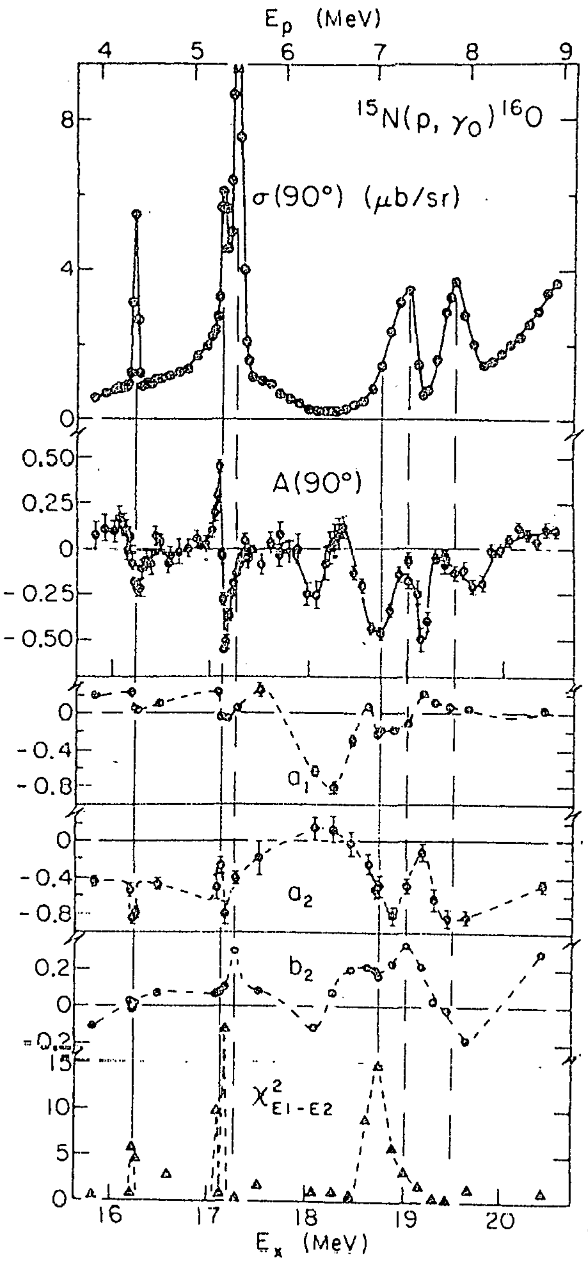

Fig. 5. Excitation curves for $^{15}N(\vec{p},\gamma_0)^{16}O$: σ(90°), A(90°) and the a_1, a_2 and b_2 coefficients (3rd and 4th order coefficients not shown) and the reduced χ^2 for angular distribution fits assuming only E1 and E2 radiation. The curves are to guide the eye. Vertical solid and dashed line lines indicate M1 and E1 resonances, respectively (ref. 21).

important restrictions on the character of the 0_2^+ state, notably its 2p-2h composition which is not known very well. Unfortunately no theoretical calculations of these decays are currently available. Hopefully the future will bring experimental investigation of higher energy resonances which undergo M1 decays to the 0_2^+ state. Particularly interesting is the question of whether a "normal" giant M1 resonance exists built on the 0_2^+ state. Weak coupling arguments along with the known ground-state M1 strength in ^{12}C and ^{20}Ne suggest such strength in ^{16}O would lie in the $E_x \sim 17$-21 MeV region.

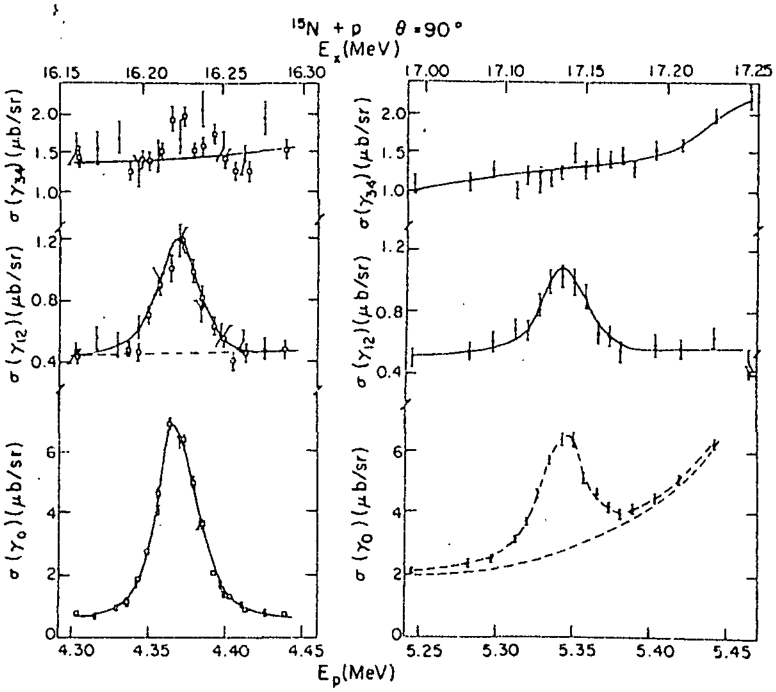

Fig. 6. $^{15}N(p,\gamma)$ yields to the 0_1^+ state (γ_0), the 0_2^+-3^- doublet (γ_{12}) at 6.1 MeV, and the 2^+-1^- doublet (γ_{34}) at 6.9-7.1 MeV, in the vicinity of the 16.22 and 17.14 MeV 1^+, T = 1 resonances (ref. 25).

M1 DECAYS TO THE GROUND AND FIRST EXCITED 0^+ STATES OF ^{40}Ca

A recent electron scattering experiment[26] has resulted in a definitive M1 assignment for a strong ($\Gamma_{\gamma_0} = 4.74 \pm 0.30$ eV, $B(M1)\downarrow$ - $0.37\ \mu_0^2$) ground state transition from a level at 10.32 MeV in ^{40}Ca. It is interesting to note that this one state in ^{40}Ca carries more M1 strength than the total of all the known ground state M1 strength in ^{16}O. This is consistent with the belief that ^{40}Ca is not as good a closed shell nucleus as ^{16}O.

The 10.32 MeV state is a well-known resonance in the $^{39}K(p,\gamma)^{40}Ca$ reaction at $E_p = 2.043$ MeV, with a capture strength $\Gamma_p\Gamma_\gamma/\Gamma = 10.3 \pm 1.7$ eV (ref. 27). This resonance strength has been used as a standard upon which other strength measurements in this mass region are based,[27] and is clearly incompatible with the radiative width quoted above. We have remeasured this capture strength with the result[28] $\Gamma_p\Gamma_{\gamma_0}/\Gamma = 4.33 \pm 0.35$ eV, compatible with the radiative width derived from electron scattering. We also observed decay branches to the excited 0_2^+ (3.35 MeV) and 2^+ (3.90 MeV) final states, with $B(M1, 1^+ \rightarrow 0_2^+)/B(M1, 1^+ \rightarrow 0_1^+) = 0.43 \pm 0.03$ and $B(M1, 1^+ \rightarrow 2^+)/B(M1, 1^+ \rightarrow 0_1^+) = 0.16 \pm 0.02$ (assuming E2/M1 = 0 for the $1^+ \rightarrow 2^+$ transition). The observed decays in ^{16}O and ^{40}Ca are shown in Fig. 7. It is truly remarkable that the reduced B(M1) branching ratios for decays to the excited 0_2^+ state relative to the 0_1^+ ground state are equal within errors for the three 1^+ states studied (the 16.22 and 17.14 1^+, 1 states in ^{16}O and the 10.32 1^+, 1 state in ^{40}Ca).

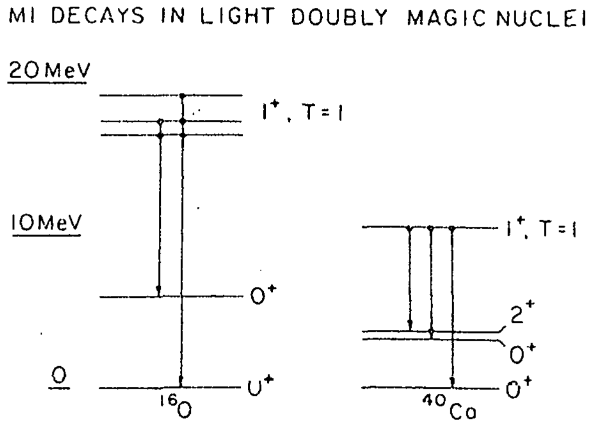

Fig. 7. Observed decays of 1^+, T = 1 states in ^{16}O and ^{40}Ca.

At Seattle, we looked for interference in $(\vec{p},\gamma)$ between this M1 resonance and the non-resonant E1 background. We did not see such effects, probably because the background is very weak and the resonance is very narrow ($\Gamma << 1$ keV). However, it is important to search for M1 strength in ^{40}Ca at higher energies, where such interference effects may be much easier to observe.

GAMMA DECAY OF THE 4^-, T = 1 STRETCHED PARTICLE-HOLE STATE IN ^{16}O

Narrow "stretched" high spin particle-hole states are found in nuclei from ^{12}C to ^{208}Pb and have been studied in high energy electron, proton, and pion scattering and in some cases in direct transfer reactions. The lowest T = 1 levels of this sort such as $[d_{5/2},p_{3/2}^{-1}](4^-1)$ in ^{12}C and ^{16}O (refs. 29, 30) and $[f_{7/2},d_{5/2}^{-1}](6^-1)$ in ^{24}Mg and ^{28}Si (see ref. 31) are believed to be predominantly 1 particle-1 hole states, which is part of the reason why they are so interesting. In ^{16}O, for example, the 4^-,1 state at 18.98 MeV has nearly all of the expected (d,t) pickup strength,[32] and has ~1/2 of the M4 "single particle" inelastic electron scattering strength.[31] However, very little is known about the decays of these levels.

Recent pickup measurements[32] and decay coincidence measurements[33] along with previous $^{15}N(p,\gamma_{12})$ measurements[34] strongly suggest assignments of 3^-, T = 1, and 4^-, T = 1 for resonances at 18.03 and 18.98 MeV in ^{16}O, respectively. We recently remeasured the capture reaction over these 2 resonances.[25] We also detected γ-rays from p_{12} and α_1 decay channels (Fig. 8) with strengths which confirm the identification of these resonances with the states seen in the pickup/decay studies. We find $\Gamma_p\Gamma_\gamma/\Gamma = 1.96 \pm 0.27$ eV and 0.85 ± 0.10 eV for the 3^-,1 and 4^-,1 resonance decays to the 3^-, 0 (6.13 MeV) final state.

Using $\Gamma_{po}/\Gamma = 0.46 \pm 0.15$ and 0.12 ± 0.05 (ref. 33) leads to $\Gamma_\gamma = 4.8 \pm 1.9$ eV and 7.1 ± 3.1 eV, corresponding to $B(M1) = 0.24 \pm 0.10\ \mu_0^2$ and $0.29 \pm 0.13\ \mu_0^2$ for the $3^-,1$ and $4^-,1$ decays to the $(3^-,0)$ level. We also obtain total widths $\Gamma = 23 \pm 12$ and 8 ± 4 keV for the $3^-,1$ and $4^-,1$ resonances, respectively, by comparing our resonance strengths for the p_{12} and α_1 exit channels with the coincidence decay results of ref. 33.

The $(4^-,1) \rightarrow (3^-,0)$ decay strength is in accord with the shell model value of $0.41\ \mu_0^2$ calculated[35] by J. Millener (using a $1\hbar\omega$ basis for the $4^-,1$ state). A real test of the 1p-1h purity of the $(4^-,1)$ level must await an improved value for Γ_γ, which depends mainly on an improved measurement of Γ_{po}/Γ. The reasonably strong $(3^-,1) \rightarrow (3^-,0)$ decay strength is also interesting since this level is not particularly strong in pickup,[32] implying it should be mostly 3p-3h.

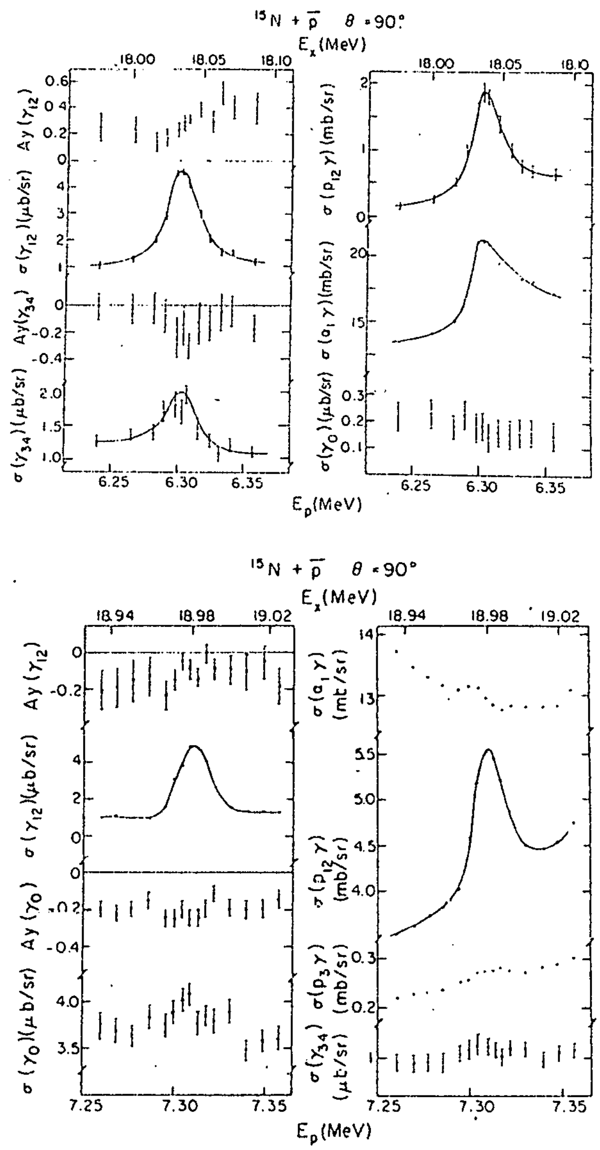

Fig. 8. ^{15}N + p yields near the 18.03 3^-, T = 1 and 18.98 4^-, T = 1 resonances (ref. 25).

Also shown in Fig. 8 is A(90°) for the capture γ-rays. Now the non-resonant background is almost certainly E1, so that one would expect M1-E1 resonance-background interference effects in A(90°), whereas the striking aspect of these data is the absence of a significant resonance in the analyzing power. The most likely explanation for this may be that the many reaction amplitudes present in the E1 background tend to wash out interference effects.

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