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OBSERVATION OF M1 STRENGTH IN MEDIUM-HEAVY NUCLEI VIA THE (p,p′) REACTION

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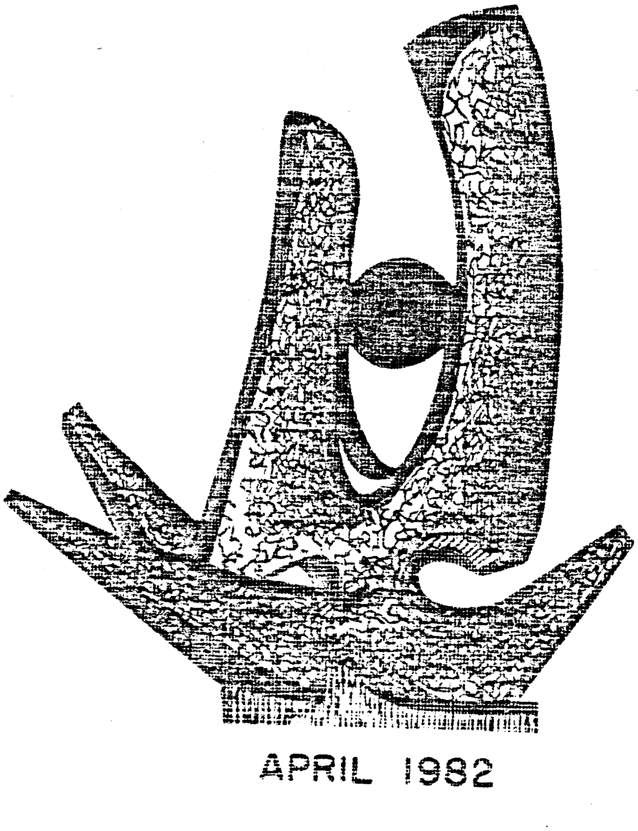

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ABSTRACT

A broad resonance has been observed by inelastic scattering of 200 MeV protons from ^{51}V, ^{58,60,62}Ni, ^{68}Zn, ^{90,92,94,96}Zr, ^{92,94,96,98,100}Mo, ^{120,124}Sn and ^{140}Ce. The resonance occurs between 8 and 9 MeV in most of the nuclei and has a width of around 2 MeV. In all cases, the angular distribution is very sharply forward peaked and is consistent with an orbital angular momentum transfer of zero. The excitation energy, angular distribution and strength of the resonance suggest that it is the giant M1 resonance. In the nickel isotopes, and in ^{51}V, both the T_o and T_o+1 components of the resonance are observed.

I. INTRODUCTION

The study of spin excitations in nuclei has been pursued by a number of different yet complementary techniques including electron scattering, (γ,n) reactions, β-decay and, more recently, (p,n), (^{3}He,t) and (p,p') reactions. The program of this conference is proof of the richness and diversity of this field. Both the beautiful (p,n) results showing the excitation of the Gamow-Teller (G-T) resonance in many nuclei[1,2] and the very nice high resolution inelastic electron scattering work[3,4,5] have stimulated renewed interest in this subject. In addition, improvements in the theoretical formulation of the effective interaction used in direct reaction calculations at high energy[6] and the resulting ability to predict the absolute magnitudes of the cross sections, confirm that magnetic transitions are substantially quenched.[7] The quenching has apparently two components, one being configuration mixing and the other more exotic mesonic effects such as the mixing of the M1 state with a Δ particle-nucleon hole configuration excited through the Δ-nucleon interaction[8,9].

In spite of the strong excitation of the G-T resonance in the (p,n) reaction, until last year there was no corresponding clear observation of the M1 state in the parent nucleus either by inelastic proton scattering[10] or inelastic electron scattering[5,11,12] in nuclei heavier than the nickel isotopes. However, the (p,n) data did suggest to us that the appropriate kinematic region to search for the M1 state in (p,p') would be at high bombarding energies (>120 MeV) and at very forward angles. The (p,n) reaction to the G-T state is very forward peaked and the similarity of the reaction mechanism suggested a similar behaviour for the (p,p') reaction. Of course, the measurement of inelastic scattering cross sections at very forward angles is experimentally challenging, primarily because of the background from scattered particles and the Landau tail of the elastic peak.

II. EXPERIMENTAL METHOD

The experiments reported here were carried out using 201 MeV protons from the synchocyclotron at the IPN, Orsay. The spectrometer attached to this facility is ideal for forward angle measurements because of its large size. In addition, a counter system consisting of two multiwire detectors and two plastic scintillators measures the trajectory of the particles emerging from the spectrometer.[13] Such measurements serve to minimize the background from scattered particles. However one problem with this counter was that it had small differential non linearities which gave rise to spurious fine structure in the spectra. For this reason each spectrum was taken with two slightly different settings of the magnetic field to clearly identify any spurious structure. An example of such overlapping spectra is shown for ^{51}V in Fig. 3a. In addition, since the fine structure was found to be very stable during a week long run, a correction function was obtained which could then be applied to all the spectra to further reduce the effect of the non linearities in the counter.

The absolute cross section was obtained in two ways. First, the cross section was measured by a comparison with the known p-p scattering cross section and second by a comparison with elastic scattering calculations at angles forward of 10°. The two methods agreed to better than 10%.

III. RESULTS

Since the T_o component of the G-T strength had been resolved from the T_o-1 component in (p,n) experiments on the Zr isotopes at 120 MeV,[1,14] a reasonably accurate prediction could be made of the position of the M1 parent state in these nuclei. The energetics are displayed in Fig. 1. The T=5, 1^+ state is about 8.5 MeV above the 0^+ I.A.S. in ^{90}Nb suggesting that the excitation energy of the corresponding M1 state in ^{90}Zr will also be about 8.5 MeV. Theoretical predictions of the excitation energy of the M1 state gave similar values.

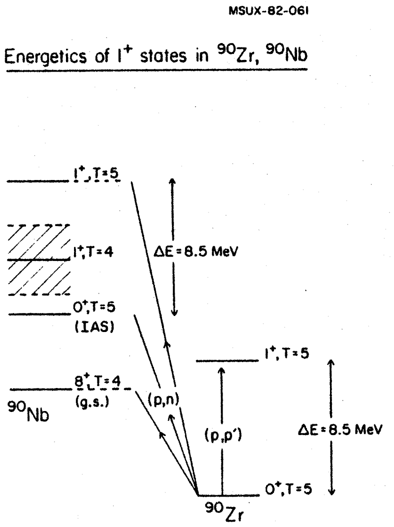

FIG. 1. Energies of 1^+ states excited in ^{90}Zr and ^{90}Nb by the (p,p') and (p,n) reactions. The excitation energy of the 1^+ T=5 state in ^{90}Zr is similar to the energy of the 1^+T=5 state above the 0^+ IAS in ^{90}Nb.

Our first measurements were therefore made on ^{90}Zr, ^{92}Zr and ^{94}Zr.[15] In all these isotopes a broad peak was observed close to the expected excitation energy of between 8 and 9 MeV (Fig. 2). A similar feature has also been observed in a (p,p') experiment on ^{90}Zr at TRIUMF.[16]

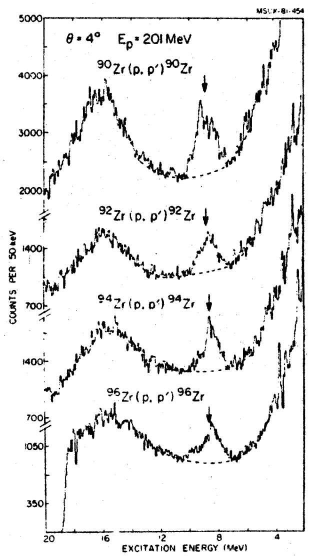

FIG. 2. Spectra of protons inelastically scattered from ^{90}Zr, ^{92}Zr, ^{94}Zr and ^{96}Zr at 4°. The arrows indicate the centroids of the M1 resonance.

In later experiments this effect was observed in ^{96}Zr[17] and in thirteen other nuclei, viz. ^{51}V, ^{58,60,62}Ni, ^{68}Zn, ^{92,94,96,98,100}Mo, ^{120,124}Sn and ^{140}Ce. Two spectra from ^{51}V, at 3° and at 8°, are shown in Fig. 3. The bump is very prominent at 3° but has practically disappeared by 8°. This feature of a very forward peaked angular distribution is characteristic of all the broad peaks observed. Unfortunately, the tail from the elastic peak increases in the heavier nuclei so that in the Sn isotopes and particularly in the Ce case, it is very difficult to extract the broad bump from the underlying smooth background even at 4°. (See Fig. 4).

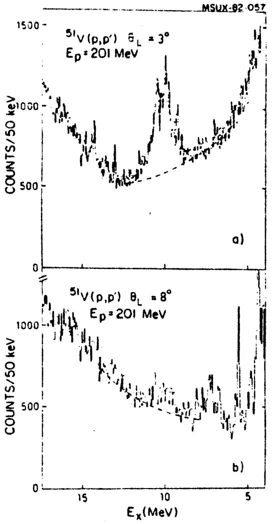

FIG. 3. Spectra of protons inelastically scattered from ^{51}V. a) at 3° and b) at 8° in the laboratory. At 3° the overlap of two spectra taken with different magnetic fields is shown. The dashed lines indicate background subtracted to obtain peak areas.

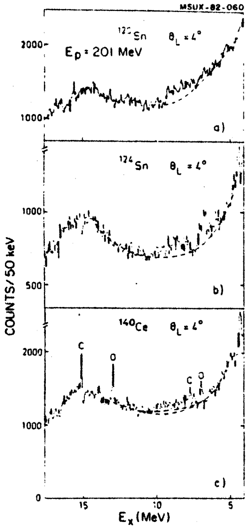

FIG. 4. Spectra of protons inelastically scattered from a) ^{120}Sn b) ^{124}Sn and c) ^{140}Ce at 4°. The dashed lines indicate backgrounds assumed in extracting peak areas. Two choices are shown for ^{140}Ce.

Angular distributions of the broad bump were measured for many of the nuclei. Some examples for the Zr isotopes are shown in Fig. 5. These angular distributions are fitted rather well by a macrosopic DWBA calculation for a $\Delta L=0$ transition as would be expected for a 1^{+} state excited by a $\Delta L=0$ spin-flip transition. An additional check is shown in Fig. 5, where a comparison is made with the ^{90}Zr(p,n)^{90}Nb angular distribution measured at a bombarding energy of 200 MeV.[20] The agreement between the (p,p') and (p,n) angular distributions is excellent back to 8° where the cross sections in both (p,p') and (p,n) reactions are down by about a factor of ten from the value at 4°. Microscopic calculations of the (p,p') reaction are also shown in Fig. 5 and these will be discussed in a later section.

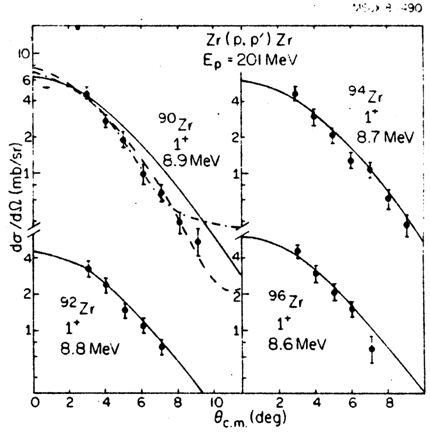

FIG. 5. Angular distributions for the M1 state in ^{90}Zr, ^{92}Zr, ^{94}Zr and ^{96}Zr. The solid (DWBA70) and dashed (RESEDA) curves are DWIA predictions, normalized to the data. The curve shown for ^{96}Zr is the calculation for ^{90}Zr. The dot-dashed curve is from a ^{90}Zr(p,n) measurement (ref. 20).

Thus both the excitation energy and angular distribution suggest that the broad bump observed systematically in a fairly large range of nuclei is indeed an M1 state. Let us now turn to a further interesting aspect of these measurements which is illustrated in the nickel isotopes.

IV. HIGHER ISOSPIN COMPONENT OF THE M1 STATE

In a heavy nucleus such as Zr, where the M1 transition proceeds by neutron excitation, the isospin of the excited state is the same as the isospin, T_0, of the ground state. However, in a nucleus with both neutron and proton valence orbits, the particle and hole couple to isospin 0 and 1, the latter then coupling to the core to produce M1 states of isospin T_0 and T_0+1. The energy splitting of these two isospin components is related to the depth of the symmetry potential V_1 by the relation

$$\Delta E = E_{T_o+1} - E_{T_o} = \frac{V_1}{A}(T_o+1).$$

The spectra observed for the ^{58}Ni, ^{60}Ni and ^{62}Ni(p,p') reactions at 4° are shown in Fig. 6. The spectra have two components, a broad peak centered near 8-9 MeV excitation energy and a strong sharp peak which moves to increasing excitation energy with increasing mass number. The broad peak is identified as the $T=T_o$ component and the sharp peak as part of the $T=T_o+1$ component of the

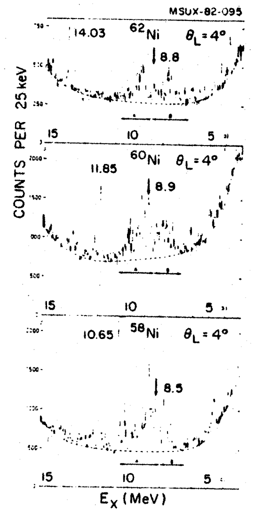

FIG. 6. Spectra of proton inelastic scattering at 4° from a) ^{62}Ni, b) ^{60}Ni, c) ^{58}Ni. The centroids of the broad bumps are shown by arrows and excitation energies are indicated in MeV.

M1 resonance. The energetics for ^{60}Ni are displayed in Fig. 7. While the 1^+,T=3 state at 11.85 MeV is above the neutron threshold, this state is isospin forbidden to decay by neutron emission. Proton decay of the state is isospin allowed but with an energy of only 2.32 MeV. The coulomb and centrifugal barriers ensure that the decay width of the state is small. Since the level density of T=3 states near 12 MeV is not large, the spreading width of the 1^+,T=3 state is also small so that the state has a narrow total width. The width measured (~70 keV) is determined by the experimental resolution.

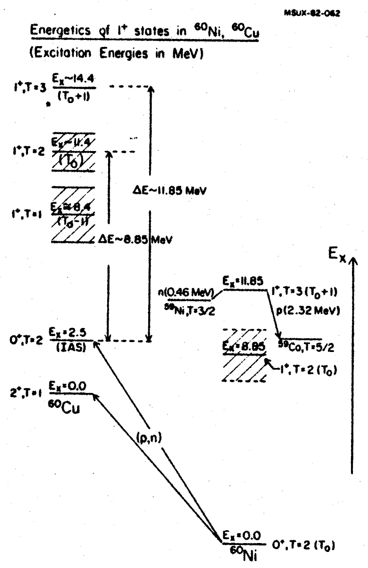

FIG. 7. Energetics of 1^+ states excited by (p,p') in ^{60}Ni and (p,n) in ^{60}Cu. The excitation energies are given in MeV. Cross hatching indicates a broad state. The decay energies for proton and neutron emission from the T=3 state in ^{60}Ni are also shown.

In order to check on these assignments, the broad peak was divided approximately in half. Angular distributions for the high energy piece (A), the low energy piece (B), the total broad resonance (Σ) and the sharp states are shown in Fig. 8. The solid lines in this figure are macroscopic DWBA calculations for ΔL=0. Forward of 6°, the theoretical curves match well the slopes of the experimental angular distributions, but at larger angles the experimental cross sections are larger than the calculations, presumably because of contributions from states of higher J^π. This effect is particularly apparent for the low excitation energy component (B) in ^{58}Ni.

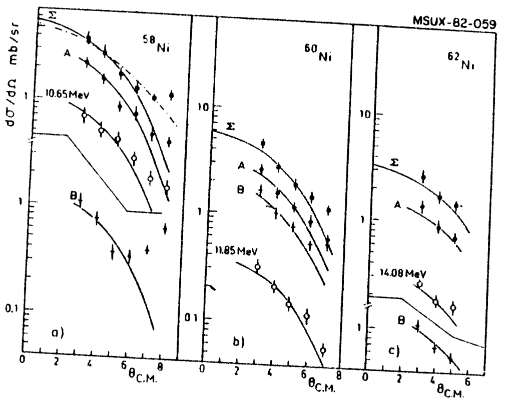

FIG. 8. Experimental angular distributions from some peaks and broad resonances in the Ni isotopes compared with macroscopic DWBA, ΔL=0 calculations. a) For ^{58}Ni, Σ which is the sum of regions A and B, is also compared with a DWIA RESEDA calculation.

If we assume that the T_o+1 component is given by the single sharp peak and that the centroid of the broad structure gives the excitation energy of the T_o component, the values of V_1 extracted are 62.4 MeV for ^{58}Ni, 59.0 MeV for ^{60}Ni and 81.1 MeV for ^{62}Ni. If all the smaller fine structure at high excitation is included in the T_o+1 component of the M1 resonance in ^{58}Ni and ^{60}Ni, the values of V_1 obtained are 82.5 MeV for ^{58}Ni and 74.5 MeV for ^{60}Ni. These values are in reasonable agreement with the estimate of V =85 MeV obtained from (p,n) measurements in heavier nuclei[21] of $E_{T_o}-1$ and the assumption that $E_{T_o} = 40A^{-1/3}$ MeV.

The relative excitation of the various isospin components of the 1$^+$ states excited in (p,p') and (p,n) reactions can be predicted using simple isospin coupling algebra. These predictions have been given recently for the Ni isotopes[22]. The energetics of the three components, T_o, T_o+1 and T_o-1, produced by (p,n) in ^{60}Cu are also displayed in Fig. 7. A recent (p,n) collaboration between Kent State and MSU on the 4 even-even Ni isotopes at IUCF[23] confirms that it is possible to observe all 3 isospin components at least in ^{58}Cu, ^{60}Cu and ^{62}Cu. The isospin splitting in these nuclei is similar to that observed in the Ni isotopes.

V. DISCUSSION

A. Excitation Energies of M1 States

A summary of the excitation energies of the M1 states observed is given in Table 1. Apart from the value in ^{51}V, the excitation energies are all very similar lying between 8 and 9 MeV. This is not too surprising since the excitation energy is expected to be determined primarily by the splitting of the spin orbit partner levels, ($j=\ell\pm\frac{1}{2}$), involved in the transition, and increased by the repulsive particle-hole interaction which stays fairly constant with mass number. The spin orbit splitting also does not change very much with mass number since the effect of decreasing ℓ.s splitting with mass is partially compensated for by the larger ℓ values involved in M1 transitions in the heavier nuclei. For example, Bertsch predicts[24] that the excitation energy of the M1 state only changes from 10.6 MeV in ^{48}Ca to 7.4 MeV in ^{208}Pb. A simple shell model calculation by Toki, Cha and Bertsch[25] also finds good agreement with the observed excitation energies of the broad resonance observed in the Zr isotopes.

B. Strength of the M1 Excitation

While the shape of the angular distribution for the broad bump can be well fitted by a macroscopic ΔL=0 DWBA calculation, microscopic calculations are needed in order to obtain the strength of the transition. Two different microscopic calculations have been made. For ^{90}Zr, ^{92}Zr and ^{94}Zr, microscopic calculations have been carried out using the code DWBA70. For ^{90}Zr, a simple $(\nu g_{7/2} g_{9/2}^{-1})1^+$ configuration was assumed. The wavefunctions used for the calculations in ^{92}Zr and ^{94}Zr were taken from a shell model calculation of Anantaraman and Wildenthal. Further details of the DWIA calculations are given in ref. 17. The ratios of experimental to predicted cross section are about 1/4 to 1/5 for the three Zr isotopes and are given in Table 1.

Independent calculations have also been carried out using the code RESEDA for the nuclei ^{58}Ni, ^{90}Zr, ^{92}Mo, ^{120}Sn and ^{140}Ce assuming simple wavefunctions in each case. Details of these calculations are given in ref. 18. The ratio of experimental to theoretical cross sections ranges from 0.46 for ^{58}Ni to 0.25 for ^{140}Ce and is also listed in Table 1. The values obtained from the RESEDA calculations are probably less reliable than from DWBA70. Exchange effects, which are known to be very significant in the calculations, are treated exactly in DWBA70 but are treated only approximately in RESEDA.

While the uncertainties in these ratios are large, both due to the uncertainties in the theoretical calculations and to the lack of a perfect fit to the experimental angular distributions, there appears to be a trend towards a decrease of the ratio as the target mass increases. This trend is consistent with the estimate of Toki and Weise[26] for the quenching due to coupling with the Δ-resonance with a finite range interaction. However, calculations with more detailed wave functions are needed before this trend can be definatively established.

Table I. Excitation Energies and Comparison with Distorted Waves Calculations for M1 States.

Nucleus	E_x(MeV) T_o	E_x(MeV) T_o+1	$N=\frac{\sigma(\text{exp})}{\sigma(\text{RESEDA})}$	$N=\frac{\sigma(\text{exp})}{\sigma(\text{DWBA70})}$
^{51}V	10.15±0.15	13.08		
^{58}Ni	8.5 ±0.1	10.65 11.36[a)]	0.46	
^{60}Ni	8.9 ±0.1	11.85 12.58[a)]		
^{62}Ni	8.8 ±0.1	14.03		
^{68}Ni	9.6±0.1 8.6±0.1			
^{90}Zr	8.9±0.2		0.41	0.26
^{92}Zr	8.8±0.2			0.19
^{94}Zr	8.7±0.2			0.26
^{96}Zr	8.6±0.2			
^{92}Mo	9.0±0.1 7.95±0.1		0.34	
^{94}Mo	8.6±0.2			
^{96}Mo	8.4±0.2			
^{98}Mo	8.5±0.2			
^{100}Mo	8.5±0.2			
^{120}Sn	8.4±0.2		0.27	
^{124}Sn	8.7±0.3			
^{140}Ce	8.6±0.3		0.25	

a) E_x for T_o+1 state if high excitation fine structure is included.

C. Comparison with (p,n) Measurements

In a nucleus like ^{90}Zr where we assume that the $j_>$ state is completely filled with neutrons and empty of protons, if we further assume that the (p,p') reaction to the 1^+ state and the (p,n) reaction to its analogue are mediated only by $V_{\sigma\tau}$, then taking the ground state isospin to be T_o, the (p,p') cross section to the 1^+ state can be compared with the (p,n) cross section to the T_o component of the G-T transition by

$$\sigma(p,p')(M1) = \frac{T_o}{2} \sigma(p,n) \ (G\text{-}T,T_o)$$

Since the (p,n) cross sections to the T_o and T_o-1 components of the G-T transition are in the ratio of $(1/(2T_o-1))$ in this model, then,

$$\sigma(p,p')(M1) = \frac{1}{4} \sigma(p,n) \ (G\text{-}T,\ T_o+(T_o-1))$$

In ^{90}Zr, the value predicted for the (p,p') cross section at 0° using the measured 0° (p,n) cross section at 200 MeV[20] is 12.5 mb/sr. Of course, there are a number of known corrections to this very simple comparison including the mixing of the (T_o-1) G-T state with lower excitation energy 1^+ states of different configurations, the contribution of the V_σ term in the (p,p') reaction and the different distortions for the outgoing proton and neutron. These effects gave about a 30% decrease (to 9 mb/sr) in the predicted cross section. An extrapolation using a DWBA calculation give a "measured" 0° (p,p') cross section of 7 mb/sr.

Thus in this simple model, there is reasonable agreement between the measured (p,p') cross section and the value expected from the (p,n) measurements.

Since the $^{208}Pb(p,n)$ cross section has been measured at 200 MeV,[20] it would be tempting to apply the same argument to predict the $^{208}Pb(p,p')$ cross section to the M1 state. However, since many neutron orbits contribute in the Pb case and also since proton excitations also contribute to the M1 excitations, the simple relationship between (p,n) and (p,p') cross sections will no longer apply. At present, inelastic proton scattering on ^{208}Pb at 200 MeV and at angles as small as 5° has not given any clear indication of M1 strength.

D. Comparison with Electron Scattering

While one might naively expect that direct comparisons could be made between (e,e') and (p,p') reactions on the same target, there are a number of difficulties both practical and theoretical with such an expectation. A comparison with earlier low resolution inelastic electron scattering on Zr[28] and Ce[29] would suggest that similar structures were excited in the two reactions. However, more detailed (e,e') experiments with better energy resolution[11,12] showed that the main multipolarity observed by backward electron scattering in these heavy nuclei was M2. There still appears to be a discrepancy between the present (p,p') results and the high resolution (e,e') data,[12] particularly on ^{90}Zr where a direct comparison can be made. While the overall strength observed in both (e,e') and (p,p') may not be inconsistent, considering the uncertainties in the DWIA predictions for the (p,p') reaction, the detailed features are quite different. A broad structure is observed in (p,p'), but only a few discrete 1^+ states are seen in (e,e'). These states would have been readily resolvable with the 70 keV resolution of the (p,p') experiment.

In lighter nuclei such as in the calcium and nickel isotopes where sharp states can be identified, the situation is still not completely clear. Let me first turn to the case of ^{58}Ni.

The excitation energies of the 1^+ states observed in two different electron scattering experiments on ^{58}Ni[11,30,31] are given in Table 2. At excitation energies above 9.5 MeV, there is overall agreement between these two experiments. In addition, they both agree with the energies found for the sharp states in the (p,p') spectra. The (e,e') studies assign an isospin $T=T_0+1=2$ to these states. However, the two (e,e') measurements differ for states at lower excitation energies. For example, in ref. 31, a single 1^+ state is found at 7.7 MeV which agrees in excitation energy with a strong state seen in (p,p'). But in ref. 30, three 1^+ states are reported at 6.05, 6.41 and 7.09 MeV. The main difference between the (e,e') and (p,p') results is that very little strength is seen in (e,e') in the region of the broad structure observed in (p,p').

For ^{60}Ni, there is general agreement in the energies of the high lying states observed in (e,e')[30] and in the present experiment. However in the electron scattering experiment, no 1^+ state is reported in the region from 6.75 to 10.75 MeV where considerable strength is seen in the (p,p') reaction.

In principle, one can obtain information on the wavefunctions of states excited in the two reactions by comparing the ratio of the observed strengths. The operators for exciting an M1 state with protons and electrons are similar particularly for neutron excitations where there is no orbital contribution to the M1 operator. In fact Crawley et al.[17] reported that the ratio of the (p,p') cross sections calculated for the M1 transitions in the Zr isotopes was very similar to the ratio of B(M1)'s calculated for the same states. These transitions were all assumed to be pure neutron transitions. Calculations using a microscopic DWIA code also show[18] that the cross sections for exciting proton or neutron particle hole configurations are very similar for the (p,p') reaction. However, this is not true in inelastic electron scattering. For example, if we assume that in ^{58}Ni the two states at 9.85 MeV and 10.65 MeV are both M1 transitions, the ratio of their strengths in (e,e') is about 1:1.3, whereas in (p,p'), the ratio of strengths is about 1:5 at 4°. These different relative strengths suggest therefore a different neutron-proton structure for these two states.

Table 2. Comparison of 1^+ States in ^{58}Ni and ^{60}Ni observed in (e,e') and (p,p') reactions. Energies are in MeV.

^{58}Ni			^{60}Ni	
(e,e') (ref. 30)	(e,e') (ref. 31)	(p,p') present work	(e,e') (ref. 30)	(p,p') present work
6.05			11.87	11.85
6.41			12.34	12.20
7.09				
	7.7	7.7*		12.73
9.85	9.852	9.82	13.11	13.25
10.18	10.224	10.18	13.35	13.55
10.55	10.515	10.48	13.84	13.99
10.66	10.676	10.65		
11.03	11.020	10.98		
	11.92	11.84		
	12.00	12.25		
		12.70		
		13.25		
	14.18			

*Only the strongest 1^+ state of the broad resonance is given in the Table.

There are also differences observed in the calcium isotopes. In ^{40}Ca, an (e,e') experiment[3,32] notes 1^+ states at 10.319 MeV and possibly at 9.868 MeV where there is probably a close doublet. In our (p,p') experiment we observe the 10.31 MeV state clearly but also observe a state with a $\Delta L=0$ angular distribution at 12.03 MeV. (See Fig. 9) The analogue of this 12.03 MeV state has also been seen in a ^{40}Ca(p,n) experiment[33] suggesting that it has $J^{\pi}=1^+$. Differences between (p,n) and (e,e') are also observed in ^{42}Ca where a single 1^+ state was reported at 11.235 MeV in (e,e') and a state at about 10.2 MeV, suggested to be 1^+, was seen in (p,n).[34] The resolution of these differences in cases where individual levels can apparently be resolved may cast light on further comparisons in heavier nuclei.

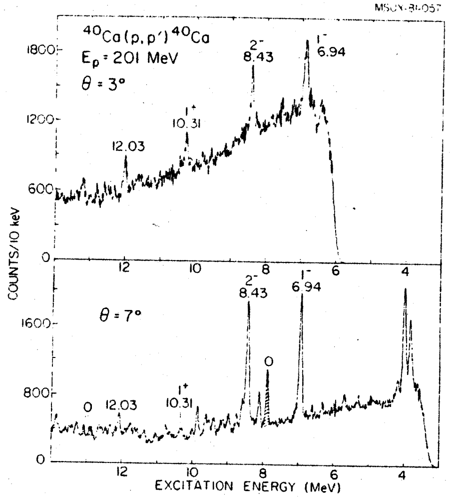

FIG. 9. Spectra of protons inelastically scattered from ^{40}Ca at 3° and 7°. Peaks due to an oxygen contaminant are shown hatched.

As a final comparison with electron scattering, a recent measurement of ^{48}Ca(p,p') at 200 MeV shows the very strong excitation of the 10.2 MeV 1^+ state at forward angles similar to the observation in (e,e') at backward angles.[3,5] The high selectivity of the (p,p') reaction is seen in Fig. 10 where the spectra at 2°, 4°, 6° and 8° are displayed. At 2° only the 1^+ state is visible, but at 8° many other levels are clearly seen. The angular distribution for the 10.2 MeV 1^+ state, which is very sharply forward peaked, is shown in Fig. 11.

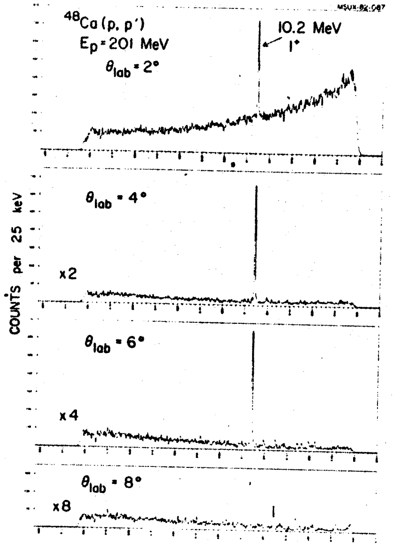

FIG. 10. Spectra from the ^{48}Ca(p,p') reaction at 201 MeV at laboratory angles of 2°, 4°, 6° and 8°.

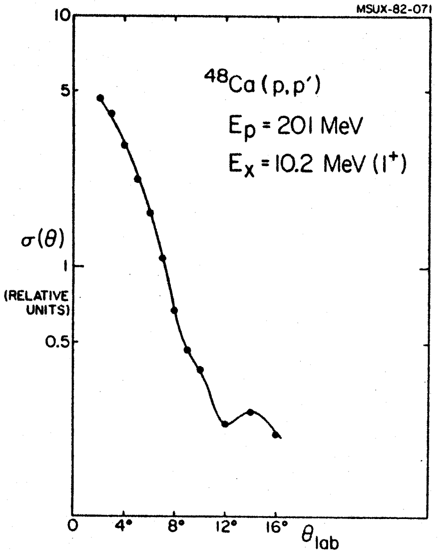

FIG. 11. Preliminary angular distributions (in arbitrary units) for the 10.2 MeV 1^+ state observed in ^{48}Ca(p,p') at 201 MeV.

VI. CONCLUSIONS AND FUTURE DIRECTIONS

Following the clue provided by the (p,n) results on G-T resonances, we have found broad structures with widths of a few MeV in seventeen nuclei from ^{51}V to ^{140}Ce using the (p,p') reaction at 200 MeV. The excitation energies of these broad bumps are consistent with those expected for an M1 transition. The angular distribution which is very forward peaked, and the strength, which is comparable to that expected from (p,n) measurements using a simple model, also support this assignment. Comparison with microscopic calculations in a few cases using simple wave functions, implies that the transitions are only about 30% of the predicted values and the ratio appears to decrease slightly with increasing target mass. The precise value of the "quenching" and particularly the mass dependence await more sophisticated calculations.

Apart from the quenching problem, there are a number of other interesting avenues which could be pursued using the (p,p') reaction at high energy.

(1) The measurement of analyzing power and particularly spin-flip probability in the region of the M1 transition would be very interesting. One might expect that the spin-flip probability would be high for an M1 transition and thus serve as an additional tool in extracting the resonance from the background.

(2) The decay of the state may also provide a means of enhancing the resonance relative to the background. There is considerable interest in finding the M1 resonance in ^{208}Pb and a coincidence measurement using the γ-decay of the state may help in such a search.

To recapitulate, the interaction between different experimental methods has proved extremely fruitful in studying M1 transitions. Both (e,e') and (p,n) data provided stimulation for the present (p,p') work. This has in turn led to other (p,n) studies searching for higher isospin components of the G-T strength and to more detailed comparisons between (e,e'), (p,n) and (p,p').

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