Possible Evidence for Gamow-Teller (or M1) Strength in $^{58}Ni(p,n)^{58}Cu$

S.M. Austin, L. Young, R. Doering, R. Bhowmik and S. Schery

The part of the effective interaction $V_{\sigma\tau}(\vec{\sigma}_i \cdot \vec{\sigma}_p)(\vec{\tau}_i \cdot \vec{\tau}_p)$ is mainly responsible for $0^+ \to 1^+$ transitions observed in (p,n) reactions. Because of the similarity of this operator to the Gamow-Teller and M1 operators in the target subspace, one expects that the strength functions for (p,n), β decay, and M1 transitions to be related.

Recently Doering, et al.[1] found evidence in the $^{90}Zr(p,n)^{90}Nb$ reaction for a concentration of Gamow-Teller strength centered about 3 MeV above the ground state analog in ^{90}Nb. This strength can also be interpreted as the anti-analog of the Giant-M1 resonance in ^{90}Zr; the analog of the M1 state should be weakly excited in a nucleus with such a large neutron excess.

In order to study these phenomena in a situation where both the analog and anti-analog of the M1 states might be observable we have examined the $^{58}Ni(p,n)^{58}Cu$ reaction at 45 MeV. Data have been taken both with resolution of about 100-150 keV (depending on E_n) and with resolution of about 1 MeV as shown in Figs. 1 and 2. In the high resolution data, (Fig. 1) one finds relatively strong excitations near the expected positions of analogs of the J = 1^+, T=2 levels of ^{58}Ni (observed near E_x=10 MeV in 180° electron scattering[2]) though the correspondence is not quite complete or unambiguous. The analogs of some of these states have been previously observed as low lying strength in the T_z=2 nucleus ^{58}Co by using $^{58}Ni(t,{}^3He)^{58}Co$[3].

The low resolution data taken at several forward angles show evidence of gross structure, with broad peaks centered near E_n=26.5 and 29.5 MeV corresponding to excitation energies in ^{58}Cu of 9.0 and 6.0 MeV respectively. This splitting is approximately consistent with the expected analog-anti-analog splitting in this mass range. However, strength seen below the 9.81 MeV state in $^{58}Ni(e,e')$ is apparently M2 in character.[2]

Future work entails measurements at other angles, especially with high resolution, in an attempt to fix the spin-parity of states dominating the observed excitations.

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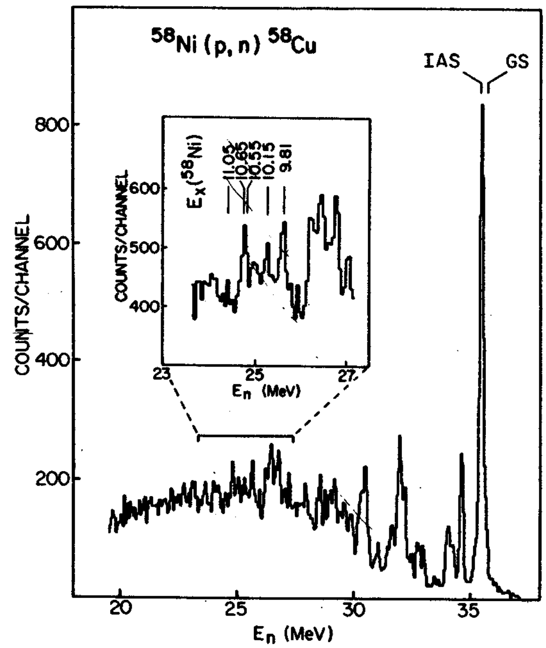

Fig. 1.--High resolution spectrum for $^{58}Ni(p,n)^{58}Cu$ at E_p=45 MeV, θ=20°. The resolution varies from ≈100 keV near E_n=25 MeV to ≈150 keV near 35 MeV. In the inset are shown the expected positions in the ^{58}Cu spectrum of the states seen in $^{58}Ni(e,e')$ at the E_x noted.

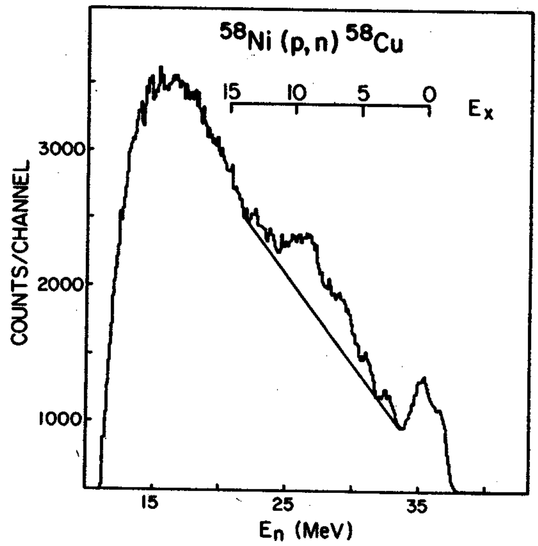

Fig. 2.--Low resolution spectrum for $^{58}Ni(p,n)^{58}Cu$ at E_p=45 MeV, θ=20°.

$^{64,66}Zn(p,d)$ Reaction

J. van Hienen and J. Nolen

In order to obtain better insight in the nuclear structure of the Zn isotopes than presently exists,[1,2] measurements of the angular distributions and energies of the out-going deutrons from the $^{66}Zn(p,d)$ ^{65}Zn and $^{64}Zn(p,d)$ ^{63}Zn reactions have been performed. The Enge split-pole spectrograph was employed together with 35 MeV protons from the MSU cyclotron. With dispersion matching and the use of thin isotopically enriched targets, energy resolutions of 4 to 7 keV (FWHM) have been obtained for the low-background deutron spectra detected by nuclear emulsions (see Fig. 1). These results lead to an accurate determination of the level energies in ^{63}Zn and ^{65}Zn up to an excitation energy of about 5 MeV. For ^{63}Zn, in particular, where the existing experimental picture was quite sketchy, many new levels have been found. In case of ^{65}Zn, previously observed levels have been confirmed in general, with several being identified as doublets. Angular distributions have been measured for 24 angles between 3° and 60° with a delay-line proportional counter system from which 13-15 keV (FWHM) resolution was obtained. From these data, absolute differential cross-sections have been obtained for many of the observed states in ^{63}Zn and ^{65}Zn. In addition to these poorer resolution measurements, the nuclear emulsion data provide angular distributions for those levels otherwise not resolved. Different shapes are found for the angular distributions of $\ell = 3$ direct reaction transfer leading to final states with $J^{\pi} = 7/2^{-}$ and $5/2^{-}$ (see Fig. 2).

Possible two-step reaction processes may account for the observed $J^{\pi} = 9/2^{-}$ and $11/2^{+}$ in this mass region. Sum rules of the observed single-particle strength for different ℓ-transfers will provide a better lower-limit on the particle occupancy numbers of the ground states of ^{64}Zn and ^{66}Zn.

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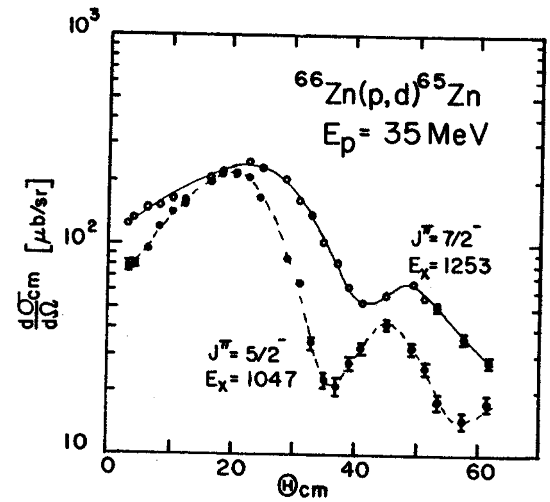

Fig. 2 Comparison of angular distributions of (p,d) transitions to final states with J^{π} = $5/2^{-}$ and $7/2^{-}$, respectively.

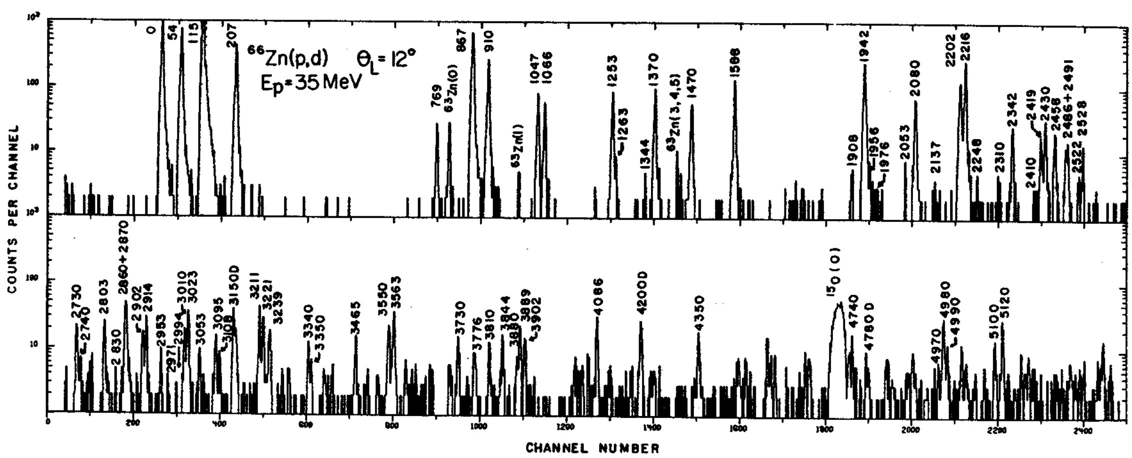

Fig. 1 Spectrum of deutrons emitted at θ_L = 12° from carbon backed ^{66}Zn target bombarded with 35 MeV protons.

Comparative Study of $(p,{}^3He)$ and (p,t) Reactions on T_z=1/2 Nuclei in the 2s-1d Shell

H. Nann and B.H. Wildenthal

During the past year work has continued on the comparative study of the $(p,{}^3He)$ and (p,t) reaction on T_z=1/2 nuclei in the sd-shell. This investigation was undertaken for two reasons. Firstly, since the wave functions of the mirror states are essentially identical, the effects of a spin and isospin dependent interaction potential in the distorted-wave Born approximation (DWBA) analysis of the two-nucleon transfer reactions can be studied by comparing $(p,{}^3He)$ and (p,t) cross sections. Secondly, since the $(p,{}^3He)$ reaction permits the transfer of a proton-neutron pair both in the singlet (S=0,T=1) and in the triplet (S=1,T=0) states, whereas the (p,t) reaction allows the transfer of two neutrons only in the singlet (S=0,T=1) state, it is possible to study in a comparative way different parts of the wave functions of the target and residual nuclei. These two aspects are coupled to each other and complicate the analysis. The accuracy of the determination of the spin-isospin term in the interaction potential depends on the reliability of the wave functions used, and, conversely, a meaningful test of wave functions can only be carried out with an accurate knowledge of this same spin-isospin dependent part in the interaction potential used in the DWBA-analysis.

We have measured angular distributions of the $(p,{}^3He)$ and (p,t) reaction on every T_z=1/2 target in the sd-shell from ^{21}Ne through ^{39}K. Microscopic DWBA calculations which employ spectroscopic amplitudes extracted from available shell-model wave functions are under way. The results will be compared with the experimental differential cross sections. For the cases analyzed so far,[1] the agreement between the predicted differential cross sections and the experimental data is generally quite satisfactory. The discrepancies observed point in some cases to inadeqacies of the shell-model wave functions used in the analysis and in other cases to some contributions from two-step processes. For example, effects from the omission of the $1f_{7/2}$ orbit in the model space are clearly seen for the nuclei studied in the upper part of the sd-shell.

In order to elucidate the effects upon the determination of the spin-isospin dependence in the transfer interaction potential which can result from different assumptions about the nuclear wave functions, different choices for the wave functions of the states involved have been tried. The influence of the spin-isospin dependence in the interaction potential was studied by considering different choices for the exchange forces using those wave functions which simulate reality most nearly.

With these assumptions the $(p,{}^3He)$ and (p,t) differential cross sections for transitions to mirror final states were calculated and compared to the experimental data. The shapes of the (p,t) angular distributions are unaffected by the choice of the strength of the spin-isospin interaction potential, whereas in the $(p,{}^3He)$ reaction the shapes of some angular distributions are makedly influenced.

A strikinly persistent feature of the (p,t) and $(p,{}^3He)$ ground state transitions has been found. We observed that for every T_z=1/2 target the $(p,{}^3He)$ ground state transition appears to proceed without appreciable S=1,T=0 transfer. Figure 1 shows all the (p,t) and $(p,{}^3He)$ ground state angular distributions with the (p,t) values elevated by one order of magnitude. The curves are results of DWBA calculations based on the current shell-model wave functions with a single set of optical madel parameters. For the $(p,{}^3He)$ reaction the contributions to the complete calculated differential cross section (solid curves) from S=0,T=1 transfer (dotted curves) and S=1,T=0 transfer (dotted-dashed curves) are shown separately. The $(p,{}^3He)$ DWBA calculations have been multiplied by the same normalisation factors which served to match the DWBA calculations to the corresponding experimental (p,t) data. The uniform result is that the S=0,T=1 pickup strength, as predicted from the measured mirror (p,t) differential cross sections, reproduces all by itself the total observed $(p,{}^3He)$ intensity. The addition of any significant amount of S=1,T=0 strength serves to make the predicted $(p,{}^3He)$ differential cross section too large, and often makes the agreement in shapes worse too. This feature is anomalous in the sense that it appears to be confined only to the ground states and that no conventional theory, either current shell-model theory or DWBA theory is able to explain it. Our ability to correctly relate (p,t) and $(p,{}^3He)$ cross sections via DWBA has been tested, of course, by analyzing differential cross sections to isobaric-analog (T=3/2) and to excited mirror (T=1/2) final states. We were able to predict correctly the relative $(p,{}^3He)$ and (p,t) cross sections in these cases.

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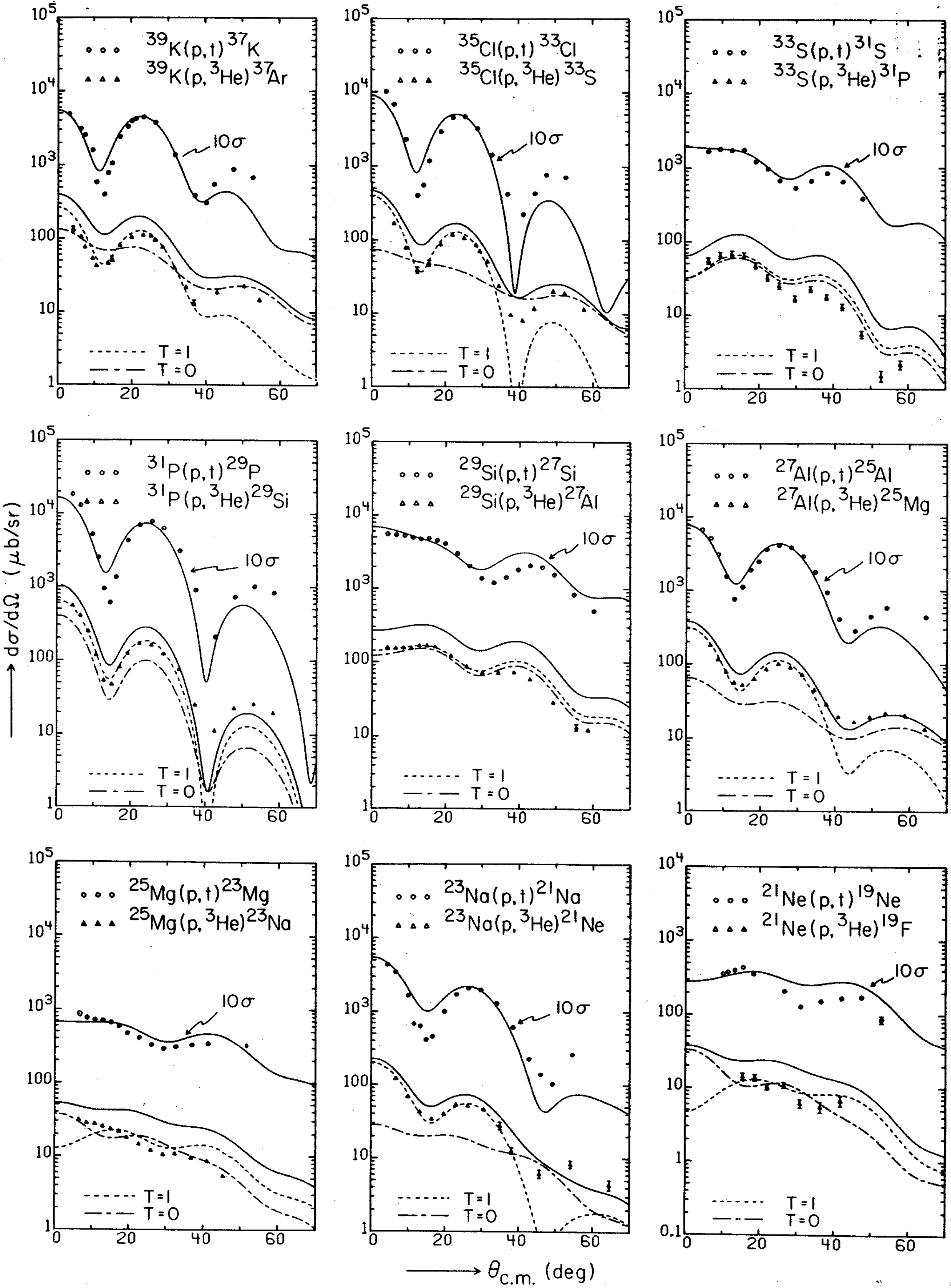

Fig. 1 Angular distributions of mirror (p,t) and (p,^{3}He) ground state transitions on $T_Z = 1/2$ nuclei in the sd dhell. The curves represent DWBA calculations based on current shell-model wave functions.

Search for Weak-Coupling Structure in (p,t) Results

H. Nann, A. Saha+ and K.K. Seth+

Recent (p,t) experiments on ^{44}Ca and ^{44}Sc have shown features which suggest a weak-coupling explanation[1]. It was found, as expected, that the ground state (J_i) to ground state (J_f=J_i) transition for the odd-A target shows a highly enhanced L=0 transfer although the selection rules allow other L-values. In addition, and not expected, a second enhanced L=0 transition to an excited state (necessarily also with J_f=J_i) was found. This state lies at an excitation energy which differs only a few hundred keV from that of the first excited 0^+ state of the adjoining even-A nucleus. The explanation of this phenomenon must arise from specific nuclear structure properties since there exist no selection rules which restrict the angular momentum transfer to L=0. It is suggested that enhancement of the L=0 transfer, the similarities of the excitation energies and, moreover, the relative magnitudes of the observed cross sections combine to indicate that this specific excited state in the odd-A nucleus is formed by the weak coupling of a nucleon to the first excited 0^+ state of the even-even core, just as the odd-A ground state is based on the ground state of the core.

The search for similar weak-coupling like phenomena has been extended to the following even-A, odd-A targets: ^{30}Si-^{31}P[2]; ^{34}S-^{35}Cl[3]; ^{40}Ca-^{39}K; ^{42}Ca-^{41}K-^{43}Ca[4]; ^{44}Ca-^{45}Sc; ^{50}Ti-^{51}V; ^{60}Ni-^{59}Ni-^{59}Co-^{61}Ni[4]; ^{56}Fe-^{55}Mn-^{57}Fe; ^{88}Sr-^{87}Sr; ^{116}Sn-^{115}In. On each even-A target nucleus about 30 angular distributions have been measured and on the odd-A nuclei about 45, totalling about 1000 angular distributions.

As an example the (p,t) reaction on ^{88,87}Sr is discussed. Figure 1 shows some angular distributions of the ^{87}Sr(p,t)^{85}Sr reaction. The curves shown are the shapes of angular distributions obtained in the ^{88}Sr(p,t)^{86}Sr reaction. The proposed weak-coupling picture is shown in Fig. 2. Here a $g_{9/2}$ neutron hole is weakly coupled to the 0.00 (0_1^+), 1.08 (2_1^+), 2.10 (0_2^+), 2.20 (0_3^+), 2.64 (2_3^+), and 2.78 (2_4^+) MeV states of ^{86}Sr. The observed strength of the transitions to the 0^+ states in ^{86}Sr matches well with that to the corresponding weak-coupling partners in ^{85}Sr. The coupling of a $g_{9/2}$ neutron hole to a 2^+ state gives rise to a quintuplet of states ranging from $5/2^+$ to $13/2^+$. Three such weak-coupling multiplets in ^{85}Sr were observed based on the first, third and fourth 2^+ states in ^{86}Sr. Here again, the observed strength matches quite well between the transitions to the core states and the corresponding weak-coupling partners.

In conclusion one can say that the weak-coupling picture, invoked to explain the shape and strength of the angular distributions of the (p,t) reaction on adjacent even-A, odd-A target nuclei, works very well in about 75% of all cases studied. The remaining 25% apply to cases where the collective nature of the "core" states is not so distinct.

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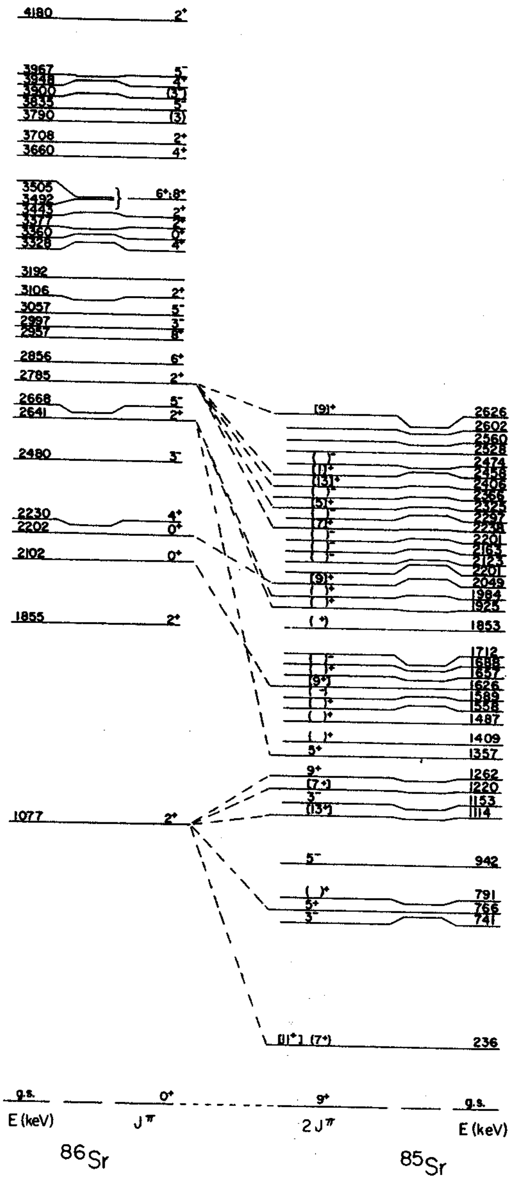

Fig. 2 States in ^{86}Sr and ^{85}Sr and their proposed weak-coupling relationship.

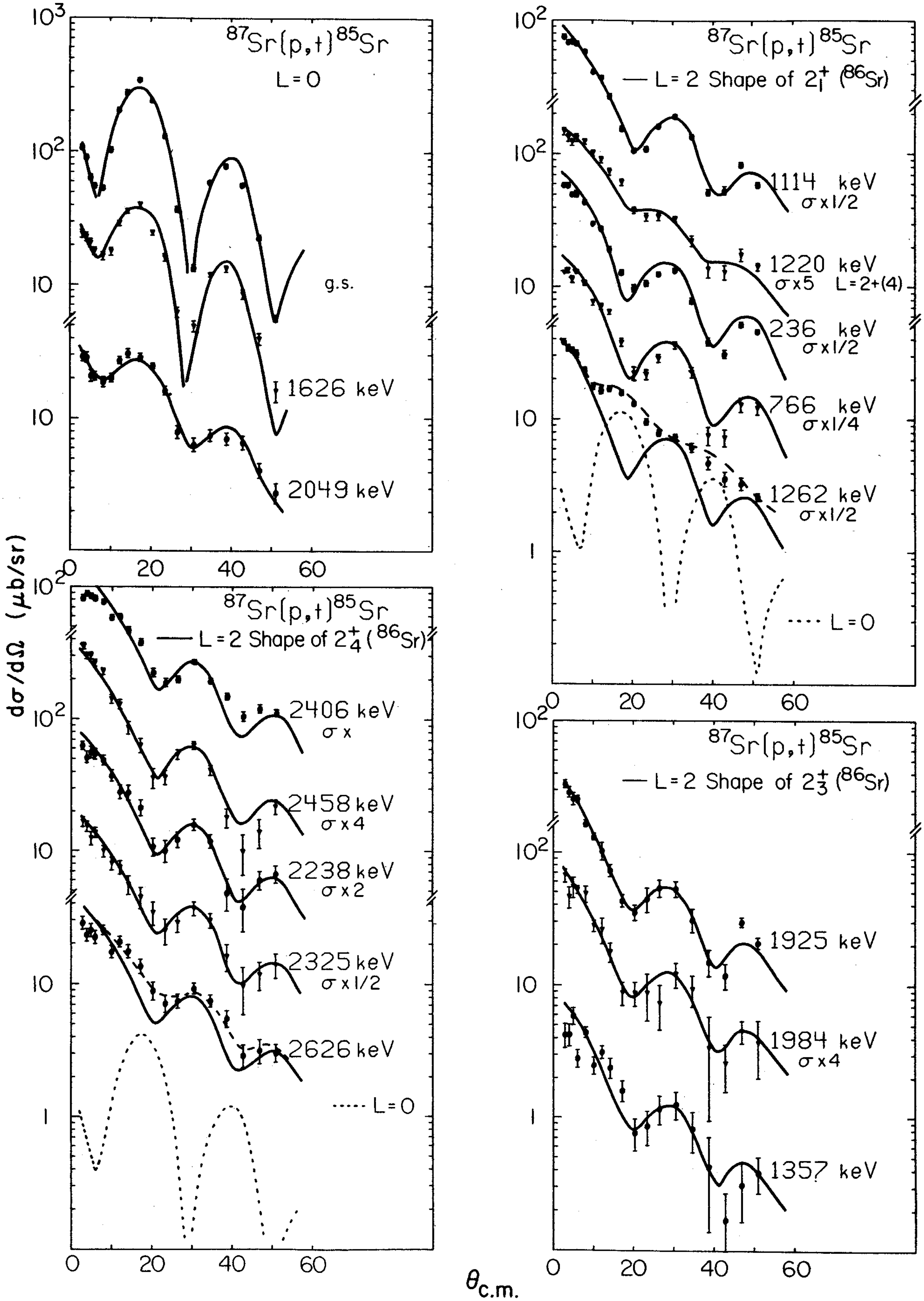

Figure 1.--Angular distributions of the ^{87}Sr $(p,t)^{85}Sr$ reaction. The curves shown are experimental shapes of angular distributions obtained from the $^{88}Sr(p,t)^{86}Sr$ reaction.

Spectroscopy in the 1f - 2p Shell With the (p,t) and (p,^{3}He) Reactions

During the last few years, many nuclei in the 1f - 2p shell have been studied with two-nucleon transfer reactions. Since the level densities in these nuclei are often quite high, even at rather low excitation energy, uncertainties and discrepancies between different experiments arose because lack of good enough experimental energy resolution.

The high resolution capability of the MSU cyclotron-magnetic spectrograph system, together with on line detectors which allow good particle identification was used to study nuclei in the 1f - 2p shell via the two-nucleon transfer reactions (p,t) and (p,^{3}He). The early data have been taken with a resistive-wire position-sensitive proportional counter in the focal plane of the magnetic spectrograph. With this type of detector, an overall resolution of 30 keV FWHM was obtained. When the slanted cathode proportional counter with delay line readout (see sect.) became available, the resolution was improved to 15 - 20 keV.

Since nuclear wave functions adequate for two-nucleon transfer do not yet exist, no complete DWBA analysis has been carried out. But in most cases the transferred orbital angular momenta L have been extracted and used to determine spins or limits on spin values for the observed levels.

A. The (p,^{3}He) Reaction

H. Nann, W. Benenson, A. Guichard and R.G. Markham

The (p,^{3}He) reaction has been studied on ^{48}Ti, ^{50,52}Cr and ^{54,56}Fe at an incident energy of 40 MeV [1-5]. The target thickness was kept in all experiments around 100 mg/cm^2. This value represents a compromise between yield and resolution.

As an example, in Fig. 1, a ^{3}He-spectrum from the ^{52}Cr(p,^{3}He)^{50}V reaction is shown. Angular distributions have been taken between 6° and 54° for transitions to states up to usually about 3.7 MeV of excitation. Figure 2 shows some of the angular distributions obtained for the ^{56}Fe(p,^{3}He)^{54}Mn reaction. The solid and dashed curves shown are DWBA calculations based on simple assumptions about the wave function of the target and final nuclei. Since the shape of the angular distributions does depend predominantly on the orbital angular momentum transfer and practically not on the configuration of the transferred nucleons, L assignments could be made and used to determine spins or limits on spin values.

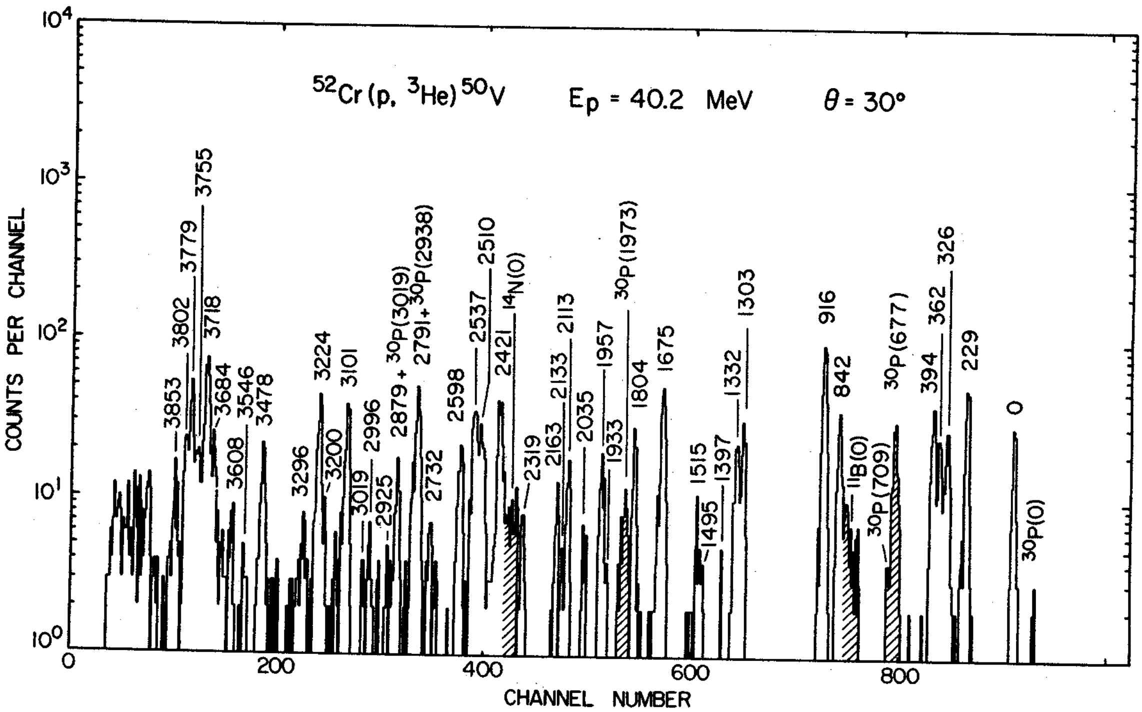

Fig. 1 Spectrum of the ^{52}Cr(p,^{3}He)^{50}V

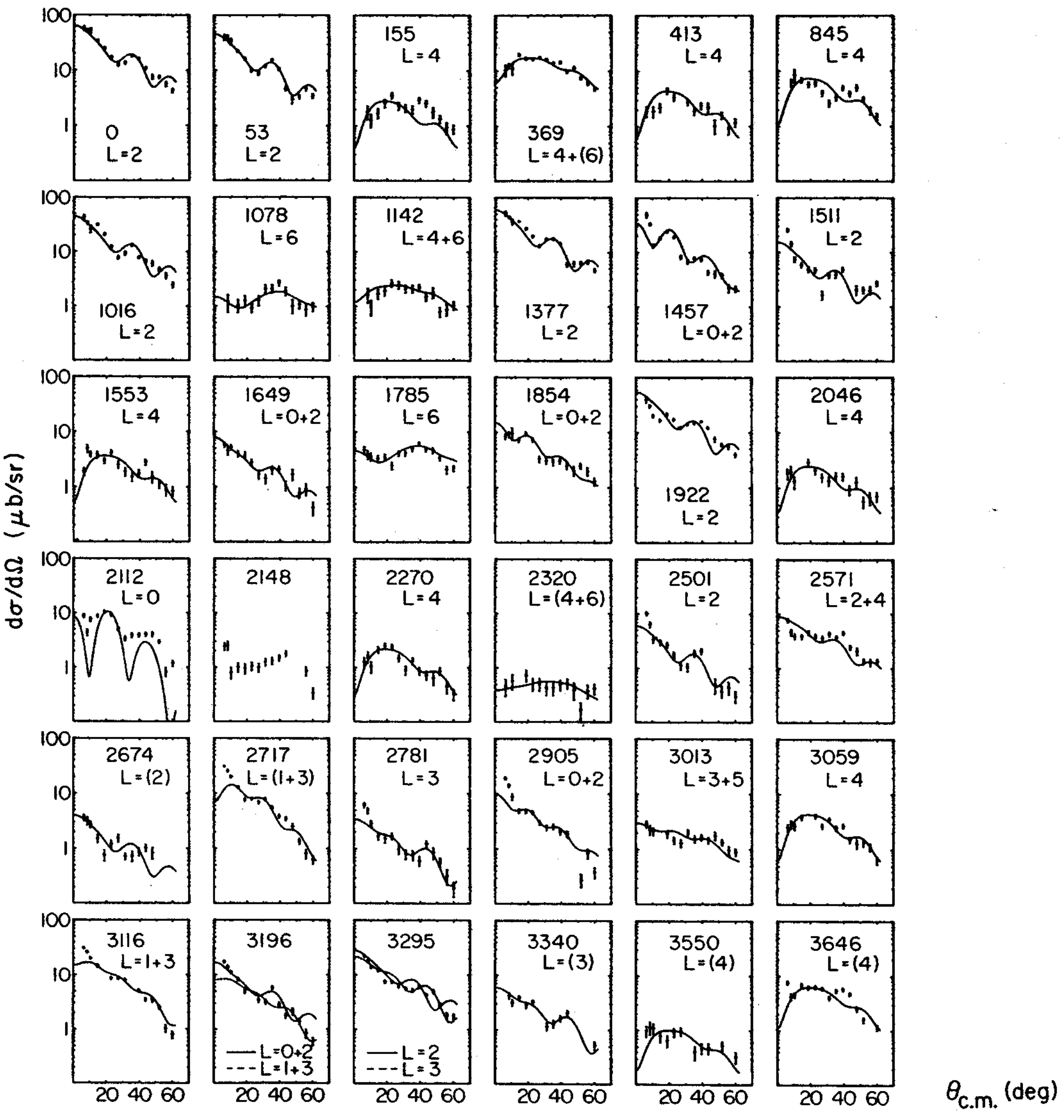

Fig. 1. Angular distributions of the $^{56}Fe(p,{}^{3}He)^{54}Mn$ reaction.

Among the many detailed results of these experiments one special case should be mentioned. By analysing the differential cross sections of the $^{52}Cr(p,{}^{3}He)$ reaction for the low lying levels of ^{50}V in terms of the DWBA based on pure $f_{7/2}$ wave functions, we were able to determine the ratio $R = |D(1,0)/D(0,1|^2$ of the spin-isospin strength of the interaction potential. An average value of $R = 0.33 \pm 0.2$ was obtained. Using a value of $D_o^2 = 25 \times 10^4$ for the overall normalization constant associated with the zero-range assumption of the interaction, we obtained $|D(0,1)|^2 = 0.62$ and $|D(1,0|^2 = 0.20$. This was the first experimental determination of these coefficients.

B. The (p,t) Reaction
H. Nann, W. Benenson, A. Saha, and P. Decowski

To date, we have studied the (p,t) reaction on $^{42,43,44}Ca$, ^{45}Sc, ^{50}Ti, ^{51}V, ^{55}Mn, $^{54,56,57}Fe$, ^{59}Co, and $^{59,60,61,64}Ni$.[6] As an example, a triton spectrum from the $^{54}Fe(p,t)^{52}Fe$ reaction is shown in Fig. 3. A resolution of about 15 keV FWHM was obtained. Angular distributions have been measured from 4° to 55°, some of which are displayed in Fig. 4. From the shapes of the angular distributions, values of the transferred orbital angular momentum L have been extracted. These L-values were used to make many new spin and parity assignments. The experimental results have been used so far only in elucidating weak-coupling relationships (described in another section) and in clarifying the general spectroscopic picture of the residual nuclei studied.

As an example, the results of the $^{54}Fe(p,t)^{52}Fe$ reaction are mentioned briefly. L = 0 angular distribution have been observed for transitions to the states at 0.00, 4.142, 5.363, 5.718, 6:634, 6.927, 8.037, 8.122, 8.561 and 10.332 MeV. Fifteen levels are found to be populated by L = 2 angular distributions: at 0.851, 2.762, 4.456, 5.828, 6.033, 6.044 6.483, 6.772, 7.463, 7.935, 8.354, 8.401, 8.900, 9.044 and 10.006 MeV. Twelve levels are excited by L = 4 angular distributions. These are the levels at 2.385, 3.583, 4.400, 5,563, 7.013, 8.146, 8.207, 8.511, 8.535, 8.748, 8.770 and 9.279 MeV. The angular distributions to the states at 4.326, 4.869, 5.652, 5.792, 7.611 and 9.059 MeV exhibit L = 6 patterns.

The excitation energies were determined with good accuracy by adjusting the magnetic field of the spectrograph in order to put each peak of interest on the same location of the focal plane. This procedure was not employed for every state, and therefore the accuracies vary from 5 to 15 keV. However, all states of particular importance were measured with the minimum error possible.

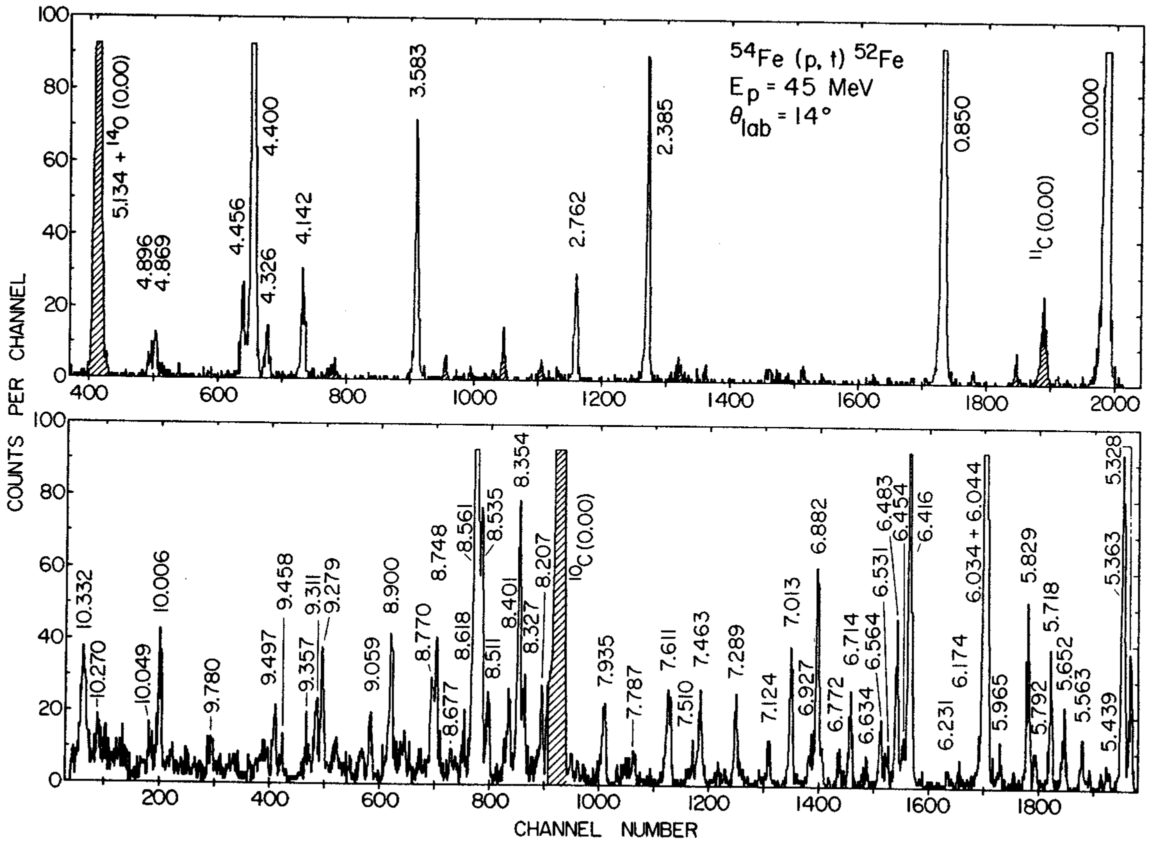

Fig. 3 Triton spectrum of the $^{54}Fe(p,t)^{52}Fe$ reaction at 45 MeV bombarding energy.

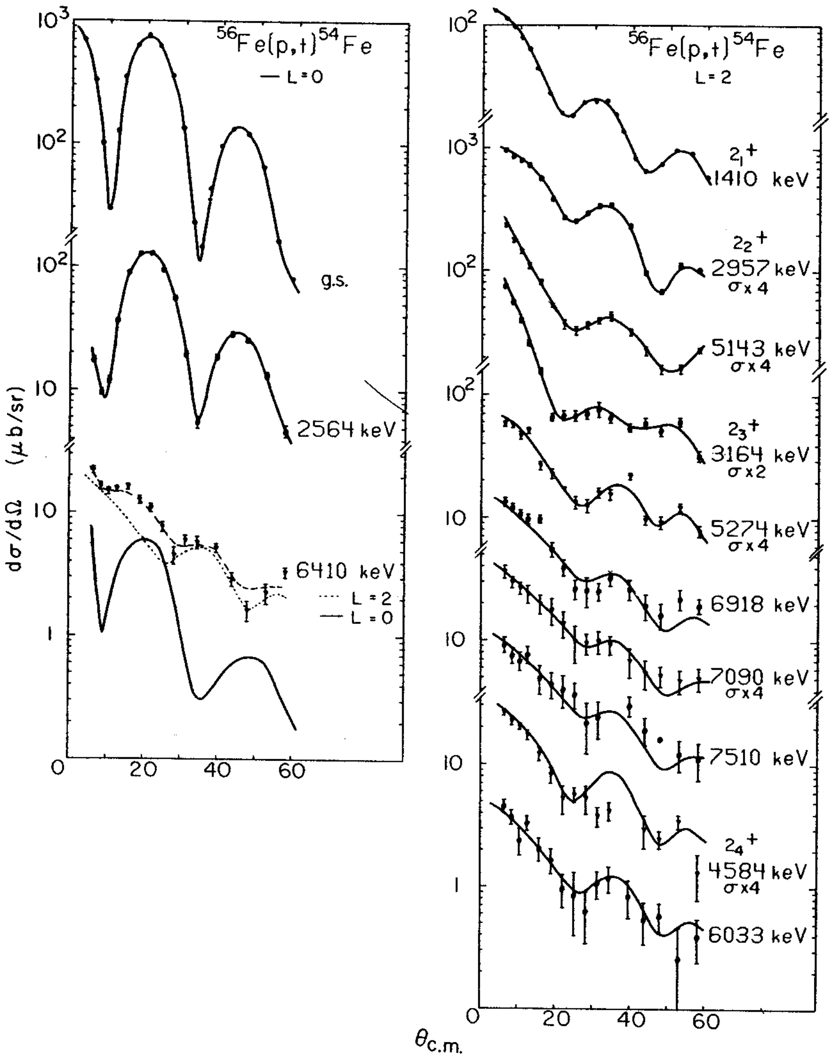

Fig. 4. Angular distributions of the $^{56}Fe(p,t)^{54}Fe$ reaction.

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A High-Resolution (p,t) Reaction Study of the Transitional Platinum Nuclides

P.T. Deason, C.H. King, F.M. Bernthal, T.L. Khoo and J.A. Nolen

A detailed understanding of the structure of nuclei in mass regions intermediate between those where nuclei have rigid deformations and those where nuclei are spherical is an unsolved problem in nuclear physics. The platinum nuclides are in one such transitional region where the transition from the deformed rare earth to the spherical lead nuclei is gradual. Attempts to explain the level structure in terms of a simple spherical vibrator or symmetric rotor have not been very successful, although recent evidence suggests that some aspects of the odd platinum nuclei can be explained in terms of a triaxial rotor description.[1-3]

The (p,t) reaction was used to initiate this study because angular distributions for the population of 0^+ states in the residual even-even nuclides have a distinctive shape. A knowledge of low-lying 0^+ states in the even platinum isotopes is basic to any distinction between the models mentioned above. In the first-order triaxial model there are no predicted excited 0^+ levels below 1 MeV whereas in a soft-nucleus vibrational model the 2-phonon triplet (0^+, 2^+, 4^+) should be found at approximately twice the excitation of the first 2^+, or one-phonon, level (∿350 keV in the platinum region).

We have measured the angular distributions of the ^{194,196,198}Pt(p,t) reactions with E_p=35 MeV, concentrating on the transitions to levels up to 2.0 MeV excitation energy (see Fig. 1). The triton spectra were recorded using a high resolution position-sensitive proportional counter[4] placed in the focal plane of the Enge split-pole spectrograph. The resolution (∿15 keV) was partially limited by the thickness of the rolled-foil targets (∿600 μg/cm^2) used to obtain these data. In addition, tritons were detected in photographic emulsions at 3 angles for each nuclide with a resolution of 6-7 keV FWHM (see Fig. 2), using thin (150 μg/cm^2) sputtered targets. At this stage of analysis no new low-lying levels, in particular no new 0^+ levels, have been found in any of the three residual nuclei (^{192,194,196}Pt) with cross sections greater than ∿0.1% of the ground state. It is interesting to note that the cross section for populating the 2-phonon 0^+ states in typical spherical vibrators (e.g. ^{112,114,116}Cd) is about 0.1 to 1% of that of the ground state.[5,6] We have also seen an unexpectedly large cross section to the 4_2^+ level (∿12% of ground state). These strong transitions to the 4_2^+ levels were not seen in the Os(p,t) reactions.[7]

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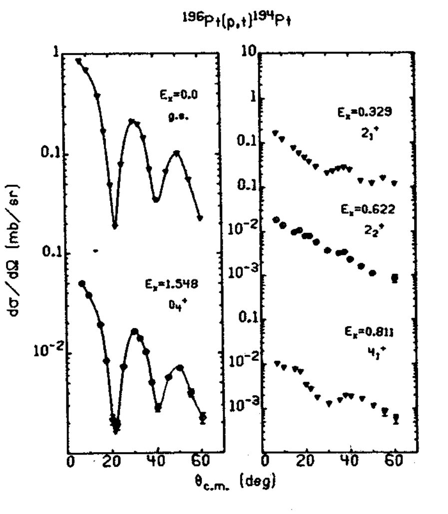

Fig. 1.--Angular distributions for some states in the ^{196}Pt(p,t)^{194}Pt reaction, measured with a position-sensitive proportional counter in the spectrograph focal plane.

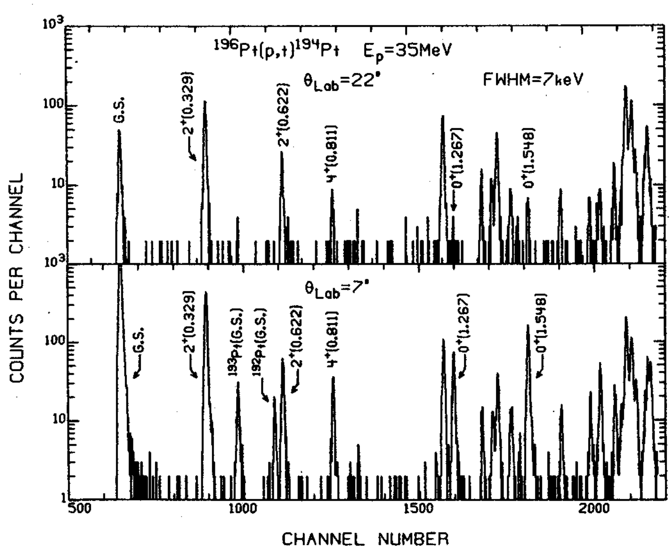

Fig. 2.--A triton momentum spectrum for the ^{196}Pt (p,t)^{194}Pt reaction obtained with a nuclear emulsion plate (FWHM=7 keV).

[Target $(3/2^+)$ x $(f_{7/2})^2_{J=7}$] Configuration States Strongly Populated in the (α,d) Reaction

H. Nann, W.S. Chien, A. Saha and B.H. Wildenthal

It is known[1] that in the (α,d) reaction the proton-neutron pair is preferentially transferred in a completely aligned configuration. Furthermore, enhanced cross sections for the transfer of large orbital angular momentum are produced due to momentum mismatch. For example, within the sd shell orbit space, levels of $J_f = J_i + (d_{5/2})^2_{J=5,T=0}$, characterized by L = 4 angular distributions, are enhanced. Likewise, at the onset of the fp shell, levels of $J_f = J_i + [(f_{7/2})^2_{J=7,T=0}$ or $(f_{7/2}p_{3/2})_{J=5,T=0}]$, characterized by L = 6 and L = 4 angular distributions, respectively, are the most prominent in the spectra.

Our work in this area has been concentrated predominantly on the odd-mass targets in the upper sd shell. We have measured angular distributions of the (α,d) reaction on ^{32,33,34}S, ^{35,37}Sc, ^{39,41}K and ^{40}Ca at 40 MeV bombarding energy. The reaction products were detected in the focal plane of a split-pole magnetic spectrograph with a position sensitive proportional counter. Figure 1 shows, as an example, a spectrum from the ^{41}K(α,d)^{43}Ca reaction. One level at 4.59 MeV of excitation clearly dominates the spectrum. The states corresponding to the largest peak in the (α,d) spectra on the different targets are at 8.84 MeV in ^{35}Cl, at 7.07 MeV in ^{37}Ar, at 5.54 MeV in ^{39}Ar, at 5.22 MeV in ^{41}Ca and at 4.59 MeV in ^{43}Ca. On the basis of the strength and the characteristic L = 6 shape of their angular distributions, which are displayed in Figure 2, it is suggested[2] that these states have a predominant [target $(3/2^+)$ x $(f_{7/2})^2_{J=7,T=0}$] configuration with spin $17/2^+$. The characteristic L = 6 shape was obtained from the ^{40}Ca (α,d)^{42}Sc transition to the well known 7^+ state at 0.62 MeV. This shape is superimposed in dashed line on the distributions of the present data.

Other observed strong transitions exhibit either pure L = 6, L = 4 or mixed L = 4 + 6 angular distributions. Some of the mixed L = 4 + 6 angular distributions are displayed in Figure 3. The L = 6 shapes can be attributed to the transfer of the proton-neutron pair in the $(f_{7/2})^2_{J=7,T=0}$ configuration. The L = 4 part can be explained by a mixture of $(f_{7/2})^2_{J=5,T=0}$ and $(f_{7/2}p_{3/2})_{J=5,T=0}$ transfer, of which the latter configuration yields a more than one order of magnitude larger cross section.

For all cases studied the present results confirm the conjectures for high-spin levels made via γ-ray spectroscopy of heavy-ion induced reactions.[3] Besides these high-spin states, many more have been found on the present (α,d) experiments.

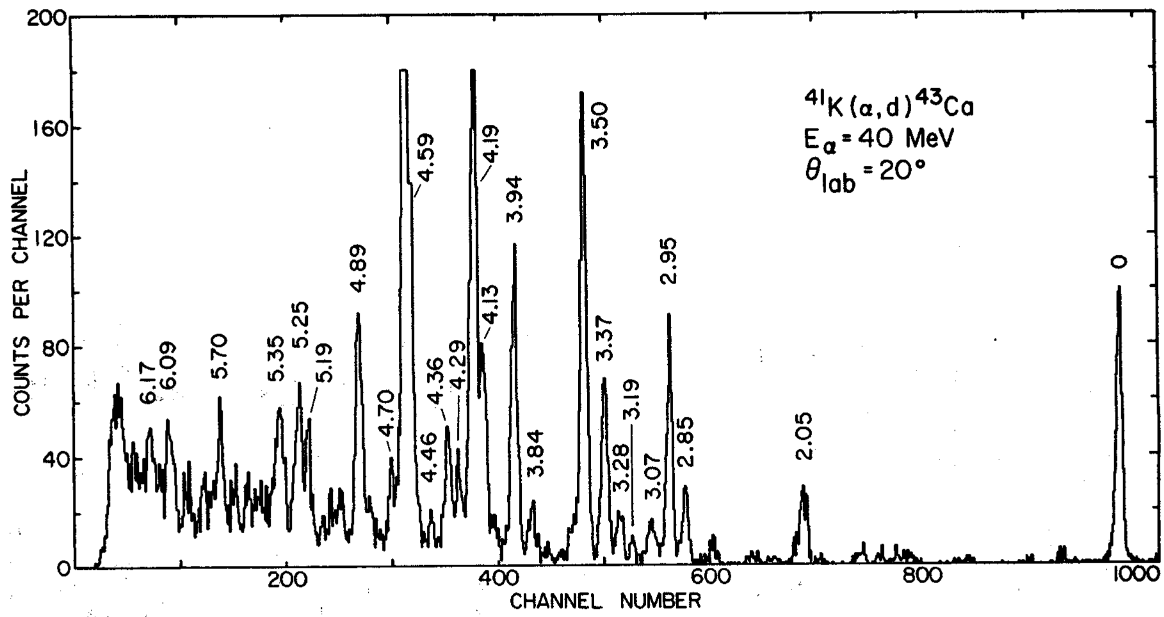

Fig. 1 Alpha particle spectrum from the ^{41}K(α,d)^{43}Ca reaction.

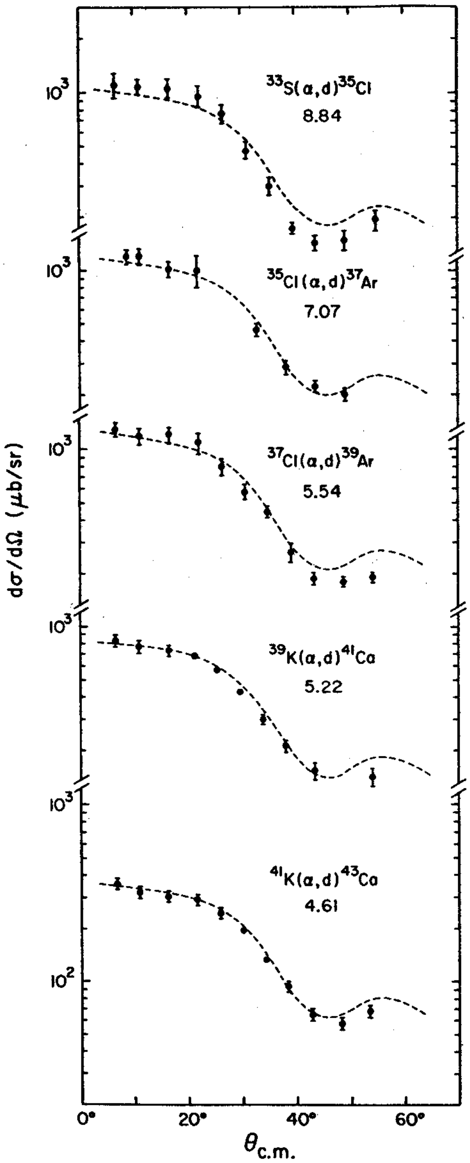

Fig. 2 The strongest L = 6 angular distributions for the various odd-mass A=33-41 target nuclei. The dashed lines represent experimental L = 6 shapes.

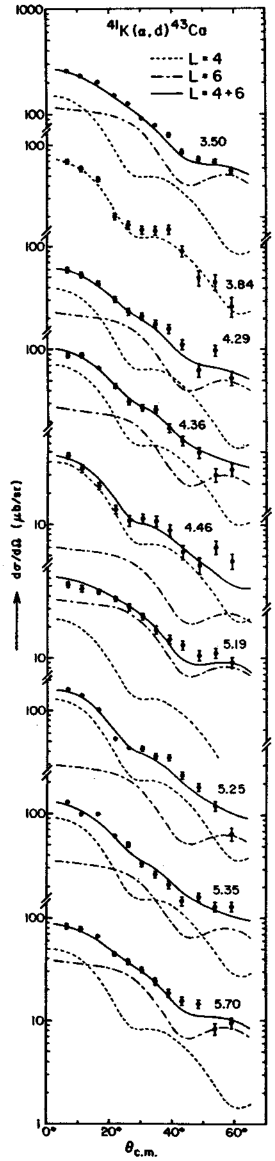

Fig. 3 Angular distributions exhibiting mixtures of L = 4 and L = 6 transfers.

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$(f_{7/2})^{-3}$ Configuration States in ^{45}Ca

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There has been a great interest in the past to describe the nuclei with Z and N between 20 and 28 in terms of the spherical shell-model with a suitable residual interaction between nucleons in a $(f_{7/2})^n$ configuration outside the closed shells. The simplest system to check the basic assumptions of such a model are the $(f_{7/2})^{\pm 3}$ configuration states. For these states, the Pauli principle allows the spins 3/2, 5/2, 7/2, 9/2, 11/2 and 15/2 with odd parity. The ordering in energy depends on the effect of the residual interaction between the nucleons beyond closed shells. Of the four nuclei in point ^{45}Ca is the least known so far.

Since, except for the $7/2^-$ state, the $(f_{7/2})^{-3}$ configurations have seniority 3, these states are very weakly excited in single-nucleon transfer reactions, but are expected to be strong in the ^{48}Ca$(^3He,^6He)^{45}$Ca reaction. Furthermore, the transitions to the high spin members of the $(f_{7/2})^{-3}$ configuration are kinematically enhanced due to momentum mismatch between the entrance and exit channels. Therefore, the comparison of the ^{44}Ca(d,p)^{45}Ca[1] and ^{46}Ca(d,t)^{45}Ca[2] single-neutron transfer reactions with the ^{48}Ca$(^3He,^6He)^{45}$Ca reaction yields evidence for the members of the $(f_{7/2})^{-3}$ configuration states in ^{45}Ca.

In Fig. 1, a comprehensive survey of the present and previous results on ^{45}Ca is shown. On the basis of our results and of an overall consistency with the available data for ^{45}Ca, we suggest that the states at 0.00, 0.17, 1.43, 1.56, 1.89 and 2.88 MeV belong to the $(f_{7/2})^{-3}$ configuration with $J^\pi = 7/2^-$, $5/2^-$, $3/2^-$, $11/2^-$, $9/2^-$ and $15/2^-$, respectively. Based on the energies of the $(f_{7/2})^{-2}$ configuration states in ^{46}Ca, the $(f_{7/2})^{-3}$ configuration states in ^{45}Ca were calculated. The results, shown in the right column of Fig. 1, agree very well with the experimental data.

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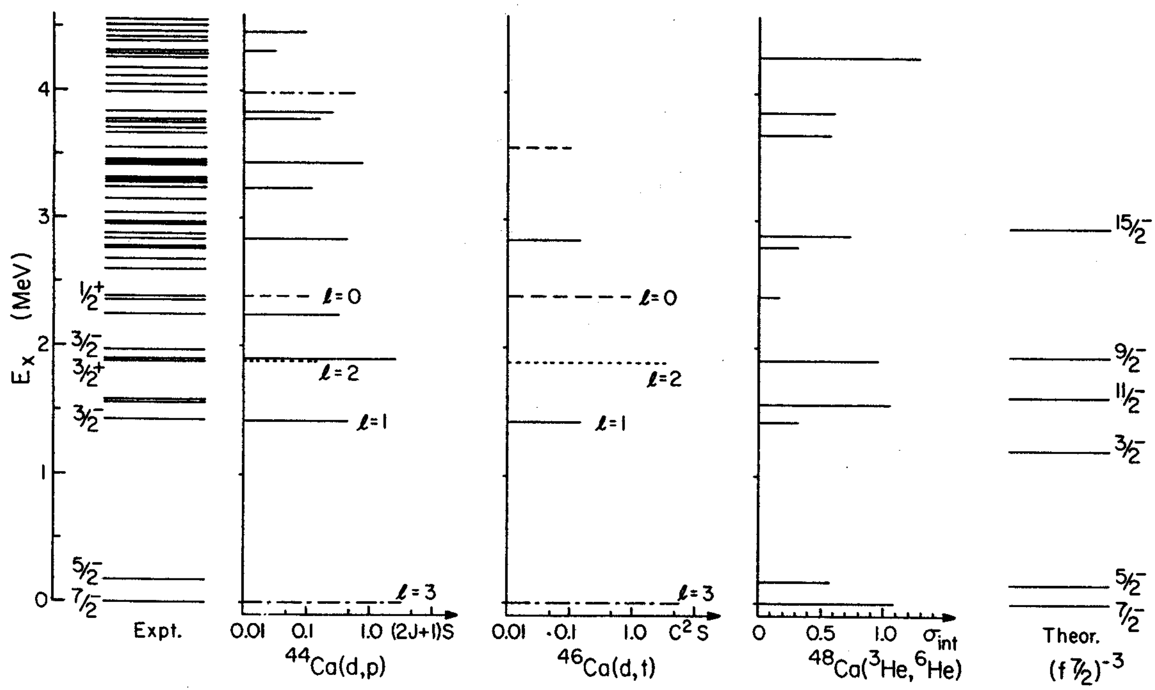

FIG. 1.--Comprehensive survey of the present and previous results on ^{45}Ca.