The $^{10}Be(d,p)^{11}Be$ Reaction at E_d=25 MeV

B. Zwieglinski[+], W. Benenson, W.R. Coker[++] and R.G.H. Robertson

The ^{11}Be nucleus has been recently studied[1] up to an excitation energy of 9.0 MeV with the $^{9}Be(t,p)^{11}Be$ reaction. Six new states in the excitation energy range from 4.0 to 9.0 MeV have been found, and the existence of those previously known[2] has been confirmed. A high-resolution study of ^{11}Be through $^{10}Be(d,p)^{11}Be$ at 25 MeV and over a similar excitation energy range has been undertaken using a target fabricated by D.R. Goosman to establish the single-nucleon parentage overlap of the states of ^{11}Be with the ground state of ^{10}Be. Protons have been detected with a delay-line proportional counter on the focal plane of the Enge split-pole spectrograph. The spectrum taken at a laboratory angle of 10° is presented in Fig. 1. The states of ^{11}Be at 0.0, 0.322, 1.79 and 3.41 MeV are excited. The latter two states are unbound with respect to neutron emission. The narrow ($\Gamma_{c.m.}$ <50 keV) states at 3.890, 3.960, 5.250 and 6.720 MeV, which were seen in the (t,p) reaction, are not excited with a significant intensity in the present work. This may corroborate the suggestion made in Ref. 1 that the transition of both neutrons into the s-d shell is involved in the excitation of these states by (t,p). An analysis of the data measured in the range of angles from 7.5 to 45° is presently under way. The separation of the 3.41 MeV state from the underlying background improves with the increasing detection angle. It is thus planned to extend the present measurements further towards backward angles to search for other broad states in ^{11}Be. Spectroscopic factors will be extracted to compare with the recent predictions of Teeters and Kurath[3] For the unbound states a DWBA analysis using continuum wave functions is planned.

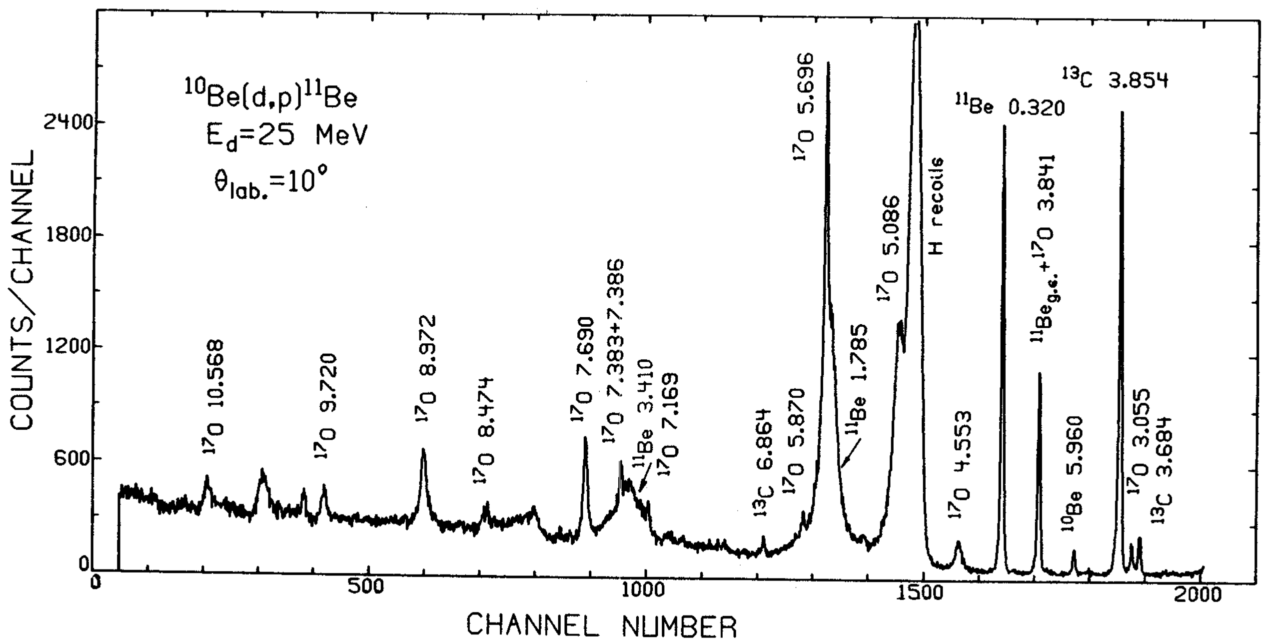

Fig. 1--Spectrum of protons from the $^{10}Be(d,p)^{11}Be$ reaction at E_d=25 MeV and a laboratory angle of 10°.

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The $^{14}C(t,p)^{16}C$ Reaction

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Low-lying levels of ^{16}C have been studied by means of the $^{14}C(t,p)^{16}C$ reaction. Bombardments were made at 15, 17, and 18 MeV using the triton beam of the University of Pennsylvania tandem accelerator. The target consisted of a gold backed ^{14}C foil (enriched to about 90%) of about 50 $\mu g/cm^2$ thickness. The outgoing protons were momentum analyzed in a multi-angle spectrograph and detected in nuclear emulsions. Absorbers directly in front of the focal plane were used to stop all particles except protons. Figure 1 shows a spectrum from the $^{14}C(t,p)^{16}C$ reaction at 18 MeV. Only the ground and 1.75 MeV state were known previously.[1] Five additional states-at excitation energies of 3.020, 3.983, 4.083, 4.136, and 6.109 MeV--were observed. States from the $^{12}C(t,p)^{14}C$ reaction were used in the calibration.

Microscopic distorted-wave Born approximation calculations were performed in order to extract values of the transferred orbital angular momentum. The g.s., 1.76, 3.02, and 4.14 MeV transitions show L=0,2,0, and 4 patterns, respectively, thus implying the spin and parity values of 0^+, 2^+, 0^+ and 4^+.

More details on this work can be found in a paper recently submitted to Physics Letters.

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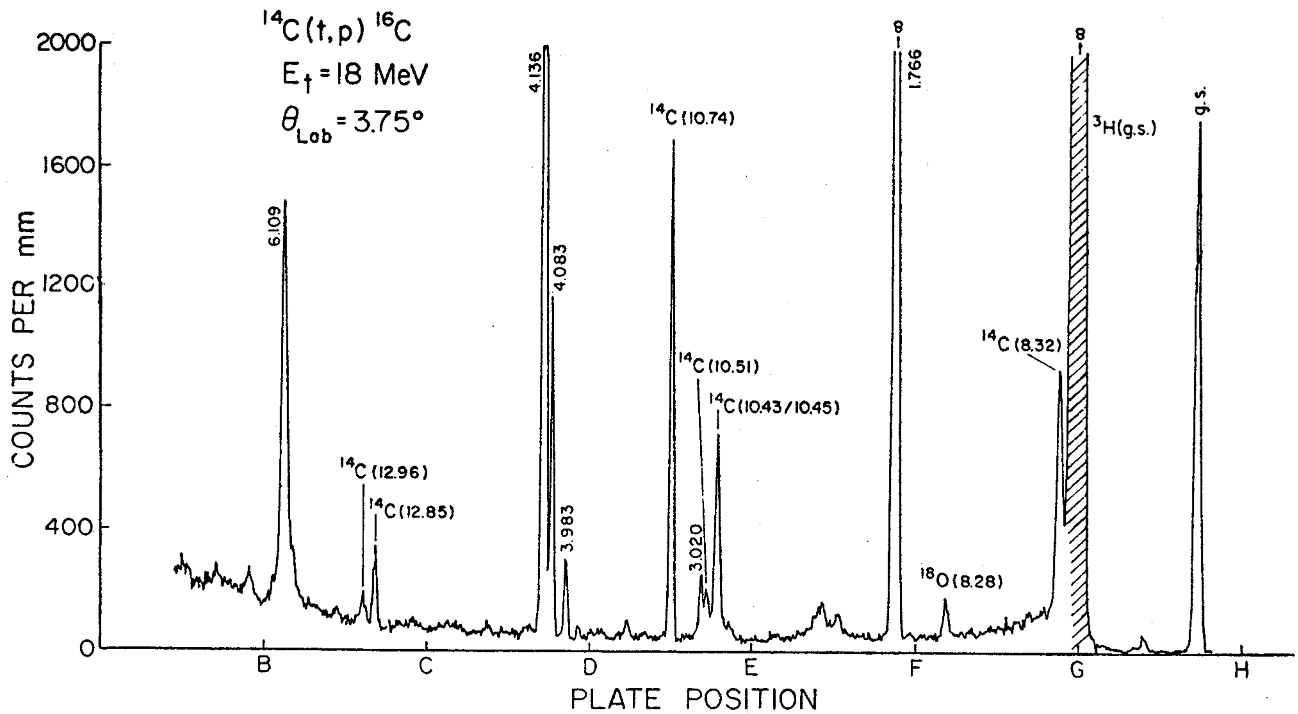

FIG. 1.--Proton spectrum from the $^{14}C(t,p)^{16}C$ reaction.

Comparative Study of the (p,t) and (p,^{3}He) Reactions on Nuclei in the sd-shell

H. Nann and B. Wildenthal

During the period of this annual report the experiments for the comparative study of (p,t) and (p,^{3}He) reactions on T_Z=1/2 nuclei in the sd-shell were completed. The microscopic distorted-wave Born approximation (DWBA) analysis of the data based on current shell-model wave functions has been started.

In the previous analyses of two-nucleon transfer reactions a strong sensitivity of the DWBA calculations to the choice of the optical-model parameters was noted. Therefore we performed a series of calculations using different optical-model parameters available from the literature.

As a first choice we took the proton optical-model parameters from the average set of Becchetti and Greenlees[1](BG). These parameters fit quite well the elastic scattering data. For the triton and ^{3}He potentials an average set from the analysis of Urone et al.[2](UPCR) was taken. With these parameters sets DWBA calculations to the ground and excited states in the ^{39}K(p,t)^{37}K and ^{39}K(p,^{3}He)^{37}Ar reactions were carried out. The results are compared in Fig. 1 (full curve) to the experimental data. The fits are not very good, especially at the very forward angles. In addition, for the ground state transitions the position of the calculated first minimum is shifted by several degrees to larger angles compared to the experimental data.

Since the optical-model parameters are quite well determined over a wide range of nuclei and energies, we kept them fixed and tried all available mass-3 optical parameters in an attempt to improve the fits to the experimental data. Somewhat surprisingly we found only small changes in the shapes of the DWBA angular distributions and were not able to improve the fits to the experimental data.

As a next step, several other proton optical-model parameters from the literature were used in the DWBA calculations. It turned out that the proton parameters from an analysis of Watson et al.[3](WSS) combined with the UPCR mass-3 parameter set improved the fits to the experimental data considerably (dashed curves in Fig. 1). It should be noted, however, that the WSS parameters do not describe the elastic scattering cross section as well as the BG parameters do.

Finally we used the proton and mass-3 optical parameters which gave good fits in previous analyses[4,5] over a wide range of nuclei from A=21 to A=88. These parameters were adapted from the works of Greenlees and Pyle[6](GP) and Morsch and Santo[7](MS). The fits to the experimental data were quite good (see dashed-dotted curves in Fig. 3). However, the GP proton parameters give a rather poor description of the elastic scattering data.

Inspection of Fig. 1 shows that either the WSS-UPCR or the GP-MS parameter combination fits the experimental data equivalently well, although the two different combinations lead to different magnitudes of the differential cross sections. However, the relative cross sections for different transitions agree to within 10%. Since little significance can presently be attached to the absolute values of the calculated two-nucleon transfer cross sections, the somewhat artificial procedure of adjusting the optical-model parameters in order to obtain good fits to the experimental transfer data does not invalidate the analysis of relative cross sections. Therefore it appears adequate merely that the DWBA results give reasonable fits to the experimental data in order to extract reliable structure information.

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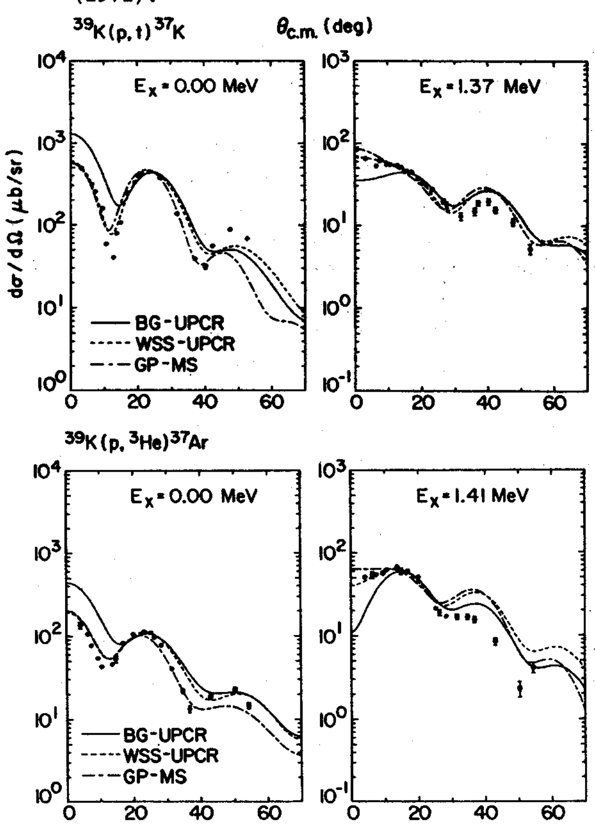

FIG. 1.--Angular distributions of the ground and first excited states transitions for the ^{39}K(p,t) and ^{39}K(p,^{3}He) reaction. The curves are DWBA results using different proton and mass-3 parameter set combinations.

The $^{22}Ne(p,t)^{20}Ne$ Reaction

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The nuclide ^{20}Ne is of particular interest because it is one of the most strongly deformed of all the light nuclides. Thus, the low-lying levels of the nucleus can be understood in terms of rotational-band structures. It is of interest to discover to what extent these levels can also be understood in terms of shell-model wavefunctions. A simple shell-model space for this nucleus is a ^{16}O closed core with two neutrons and two protons in the 1s-0d shell. This space cannot account for the low-lying negative-parity levels of ^{20}Ne, which clearly require excitations of particles from the ^{16}O core. At some point such core-excitations should affect the positive-parity levels as well.

Transfer reaction experiments form one means of testing the wave functions of nuclei, and with this in mind we have examined the $^{22}Ne(p,t)$ reaction. Past measurements[1] of this reaction have concentrated mainly on the cross sections for exciting the levels below 6 MeV. Below this energy, the positive-parity levels all fit into a ground-state ($K = 0^+$) rotational band. Because of the high collectivity of these levels as well as the low-lying levels of ^{22}Ne, it is necessary in a reaction analysis to account for multistep processes involving intermediate inelastic excitations. When this is accomplished by means of coupled-channel Born approximation (CCBA) calculations, however, it is found[2] that the cross sections for transitions to the ground state band members are adequately explained soley in terms of 1s-0d wave functions. We have continued the measurements and analysis up to 12 MeV excitation in ^{20}Ne.

We measured cross sections for $^{22}Ne(p,t)$ in the 4 to 12 MeV excitation region using 40 MeV protons. The target consisted of a gas cell containing 99.9% purity ^{22}Ne, and the outgoing tritons were measured in a single-wire proportional counter in the focal plane of our Enge split-pole spectrograph with a double-slit arrangement at the entrance aperture to eliminate particles coming from the gas-cell window. The average energy resolution was 60 keV FWHM, resulting mainly from the finite size of the target. Most of the positive-parity levels between 6 and 12 MeV can be fit into two excited $K = 0^+$ bands. The 0^+ level at 7.20 MeV is weakly excited and we were unable to resolve it from the nearby 3^- level at 7.17 MeV.

To analyze the transitions to these levels we used CCBA calculations with the two-nucleon transfer form factors determined from shell-model wave functions and inelastic form factors parameterized according to the collective model. This method was found to work reasonably well for the transitions to the ground-state rotational band[2]. For those calculations the deformation parameters of the collective model were chosen so that the cross sections for inelastic scattering were reproduced in a collective-model coupled-channel analysis. However, as is clear from the difference in their moments of inertia, the deformation parameters for the ground-state band of ^{20}Ne are not likely to describe the excited bands also. The shell-model calculations predict smaller B(E2)'s for these bands than for the ground band. Thus, we have chosen the quadrupole deformation (β_2) in each case to be reduced from that of the ground band by the ratio of the square root of the calculated B(E2; $0\rightarrow2$) to that of the ground band. For simplicity we ignored higher order deformations.

The calculations for the second $K^\pi = 0^+$ band used wavefunctions in a $d_{5/2}$-$s_{1/2}$-$d_{3/2}$ model space. The calculated cross sections reproduce the magnitudes of the experimental cross sections reasonably well although the shapes are poorly reproduced. We have found, however, that these shapes are very sensitive to the value of β_2 for this band. Thus, because of the uncertainty in determining the deformation parameters, the discrepancies in angular distribution shapes are not particularly surprising.

When $d_{5/2}$-$s_{1/2}$-$d_{3/2}$ model space wave functions were used in a calculation for the transitions to the third $K^\pi = 0^+$ band, the resulting cross sections were an order of magnitude too small. Calculations were also performed using a $p_{1/2}$-$d_{5/2}$-$s_{1/2}$ model space for determining the transfer form factors. The magnitudes of these calculated cross sections are in reasonably good agreement with the data. This suggests that excitations from a closed $p_{1/2}$ shell are necessary to describe the wave functions of the states of the third 0^+ band. This result is consistent with other known experimental data on this band.[3]

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Microscopic Analysis of the $^{24,26}Mg(p\alpha)$ Reactions

R.G. Markham, R.K. Bhowmik, P.A. Smith, M.A.M. Shahabuddin and J.A. Nolen, Jr.

These experiments have been described in the last annual report. At that time it was pointed out that there was a set of transitions that were analogous in the two reactions. The final states were at about the same excitation energy and displayed the same angular distributions. At the same time it was also noted that the ^{24}Mg cross sections were considerably stronger and that in each nucleus states of the same J^π frequently had very different angular distributions. Aside from possible kinematic effects, these observations suggest a strong dependence on the microscopic structure of the nuclei. In this past year we have studied the effect of microscopic structure by calculating the cross secions via shell model wave functions, microscopic three nucleon form factors and zero range DWBA.

The form factor is a coherent sum of contributions from different configurations, each term being the joint probability amplitude that the initial and find nuclear states differ by the three nucleon configuration and that at each position of the center of mass of the three nucleons the internal motion corresponds to the internal motion in the exiting alpha. Hence the form factor for pickup can be written as

$$F^J(\vec{R}_{cm}) = \sum_\Gamma \langle initial || \psi^\Gamma || final \rangle f^\Gamma(\vec{R}_{cm})$$

where Γ represents all the quantum numbers necessary to describe three nucleons in a shell model configuration ψ^Γ and $f^\Gamma(\vec{R}_{cm})$ is given by the integral over the internal "triton" coordinates $(\vec{\zeta}_1, \vec{\zeta}_2)$

$$f^\Gamma(\vec{R}_{cm}) = \int d\vec{\zeta}_1 \int d\vec{\zeta}_2 \; \psi^\Gamma(\vec{r}_1, \vec{r}_2, \vec{r}_3)\phi_t(\vec{\zeta}_1, \vec{\zeta}_2)$$

The integral is done numerically via a generalization of the technique of Bayman and Kallio for two nucleon transfer. We also use Woods-Saxon single particle wave functions and a gaussian triton wave function ϕ_t. No correction is made for the use of fixed center wave functions and pn quantum numbers are used to simplify the integral.

The nuclear overlap in eq. 1 is then a pn matrix element between states of good isospin. These unusual matrix elements can be readily evaluated by expressing ψ^Γ in terms of states of good JTT_z using an intermediate state decomposition so that each matrix element becomes a sum of products of single nucleon and two nucleon isospin matrix elements. The set of intermediate states was kept moderately small by choosing them to be the first eight eigenstates of each allowed JT.

The results of these calculations are shown in Table 1. The relative cross sections are rather well reproduced with the exception of some weakly populated states and the over prediction of the ^{24}Mg cross sections relative to those of ^{26}Mg. This over prediction seems to be traceable to the use of the same set of single particle functions for both reactions despite a 5 MeV Q-value difference. As was hoped at the outset, the angular distribution shapes are sensitive to the nuclear structure. The predicted distributions are not all the same; unfortunately, they are not always in full agreement with the data.

TABLE 1.--Results of microscopic analysis.

Target	J^π	State #	E_x (MeV)	Theor. Spect. Factor$^{a)}$ ($x10^3$)	D_0^2 Absolute$^{b)}$	D_0^2 Relative$^{c)}$
^{26}Mg	$1/2^+$	1	2.39	0.59	1090	0.12
	$1/2^+$	2	4.43	0.76	14400	1.65
	$1/2^+$	3	6.31	1.61	5450	0.62
	$3/2^+$	1	0.00	0.035	38800	4.43
	$3/2^+$	2	2.98	0.53	6240	0.71
	$(3/2^+)$	(3)	5.38	(0.53)	(6318)	(0.72)
	$5/2^+$	1	0.44	16.9	8750	1.00
	$5/2^+$	2	3.91	0.77	2470	0.28
	$(5/2^+)$	(3)	5.38	(0.07)	$(1.02x10^5$	(11.7)
	$7/2^+$	1	2.08	2.22	5180	0.59
	$7/2^+$	2	4.78	$4.7x10^{-3}$	$2.4x10^6$	278
	$(7/2^+)$	(3)	6.04	(.14)	(36784)	(4.2)
	$9/2^+$	1	2.70	9.83	9490	1.08
	$11/2^+$	1	5.54	0.84	27700	3.17
	$13/2^+$	1	6.24	14.8	16900	1.93
^{24}Mg	$1/2^+$	1	2.43	36.3	175	0.020
	$3/2^+$	1	0.00	8.28	1190	0.014
	$3/2^+$	2	4.47	0.15	25300	2.89
	$5/2^+$	1	0.33	156	703	0.080
	$5/2^+$	2	3.54	6.11	1230	0.14
	$7/2^+$	1	1.72	10.1	1041	0.12
	$(7/2^+)$	(2)	6.50	(10.0)	1064	0.12
	$(7/2^+)$	(3)	6.50	(0.55)	16640	1.90
	$9/2^+$	1	2.83	6.04	4420	0.50
	$(13/2^+)$	(1)	6.60	(85.4)	(3500)	(0.40)

a) $\int_0^\infty F^J(R)\;^2R^2dR$

b) $D_0^2=(2J+1)\;\frac{d\sigma}{d\omega}_{exp}/\frac{d\sigma}{d\omega}_{DWUCK}(10^4MeV^2/F^3$.

c) values of D_o^2 relative to the $^{26}Mg, 5/2_1^+$ state.

Proton Particle-Hole States in ^{28}Si Excited by the $^{27}Al(^3He,d)^{28}Si$ Reaction

H. Nann

In the simple shell model picture the $1d_{5/2}$ shell is filled at ^{28}Si. To the extent that the ground state of ^{27}Al can be described as a pure $d_{5/2}$ proton hole, and the stripping reaction mechanism is not expected to excite the core appreciably, the states in ^{28}Si reached by the $^{27}Al(^3He,d)$ reaction should be those of simple $(1d_{5/2})^{-1}$ $(2s_{1/2}, 1d_{3/2}, 1f_{7/2}$ or $2p_{3/2})^1$ proton particle-hole configurations.

The $^{27}Al(^3He,d)^{28}Si$ reaction has been studied at 35 MeV bombarding energy with an overall energy resolution of about 30 keV FWHM. Angular distributions were obtained from 6^o to 55^o for levels up to 15.5 MeV in excitation. Distorted-wave Born approxiamtion (DWBA) calculations were performed using the optical-model parameters reported by Barnard and Jones.[1] These parameters fit the data quite well. The strongest excited states are collected in Table I together with the extracted values of the transferred orbital angular momentum ℓ_p.

Special attention was given to ℓ_p=3 transitions, since they lead to states with a predominant $(d_{5/2}^{-1}\ f_{7/2}^{1})$ particle-hole configuration. From the work of Neal and Lam,[2] Dalmas et al.[3] and Meyer etal.[4] several negative parity states with spins 4^-, 5^- and 6^- are known above 8 MeV of excitation. These states are very strongly excited in the present experiment with ℓ_p=3. This confirms the conjectures about their configuration made in the above mentioned papers. The 6^-, T=0 and 6^-, T=1 states at 11.58 and 14.36 MeV are excited by nearly the same strength supporting the assumption that their configuration is pure $(d_{5/2}^{-1}\ f_{7/2})_{J=6}$.

Table I. The strongest excited states seen in the $^{27}Al(^3He,d)^{28}Si$ reaction.

E_x(MeV)	J^π(Ref.[4,5])	ℓp
6.27	3^+	0+2
6.88*	$3^-;4^+$	2
7.34	2^+	0+2
8.59	3^+	0+2
9.31	3^+,T=1	0+2
9.38	2^+,T=1	
9.49*	$2^+;(1,2)^+$	2
9.70	5^-	3
10.37	$(3)^+$,T=1	2
10.89*	1^+,T=1	2
10.07		
11.43*	4^-	1+3
11.58	6^-	3
11.66	2^+	
11.893	(4^+),T=1	2
11.97		2
12.19	3^-	1
12.48	3^-	3
12.66*	$(4^-);4^-$,T=1	3
12.74	3^-,T=1	1
13.25*	$3^-;5^-$;T=1	3
13.98*		3
14.36	6^-,T=1	3
15.12		3

*doublet

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High-Spin States of $(fp)^2$ Character in the Upper sd-Shell

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

The preferential excitation of high spin states in the (α,d) reaction at suitable bombarding energies can be used to identify those states and, furthermore, to infer their main configurations. At the onset of the fp shell, levels with

$$(\text{target})_J \otimes (f_{7/2})^2_{J=7,T=0}$$

configuration are expected to be strongly excited by L=6 angular distributions. The observation of strong L=4 transitions can be attributed to a mixture of

$$(\text{target})_J \otimes (f_{7/2}\, p_{3/2})_{J=5,T=0}$$

and

$$(\text{target})_J \otimes (f_{7/2})^2_{J=5,T=0}$$

configurations in the final state.

We have measured the (α,d) reaction on ^{32}S, ^{33}S, ^{34}S, ^{35}Cl, ^{37}Cl, ^{39}K, ^{41}K, and ^{40}Ca at 40 MeV bombarding energy. Angular distributions were taken over the region from 6° to 55°. Using the experimental L=6 and L=4 shapes obtained from the ^{40}Ca (α,d) reaction leading to the known 7^+ and 5^+ states in ^{42}Sc at 0.62 and 1.51 MeV, respectively, the expected L=6 and L=4 angular distributions were identified. An example is shown in Fig. 1.

The results for the different target nuclei can be found in a series of publications in Physics Letters,[1] Physical Review,[2,3] and Nuclear Physics.[4,5]

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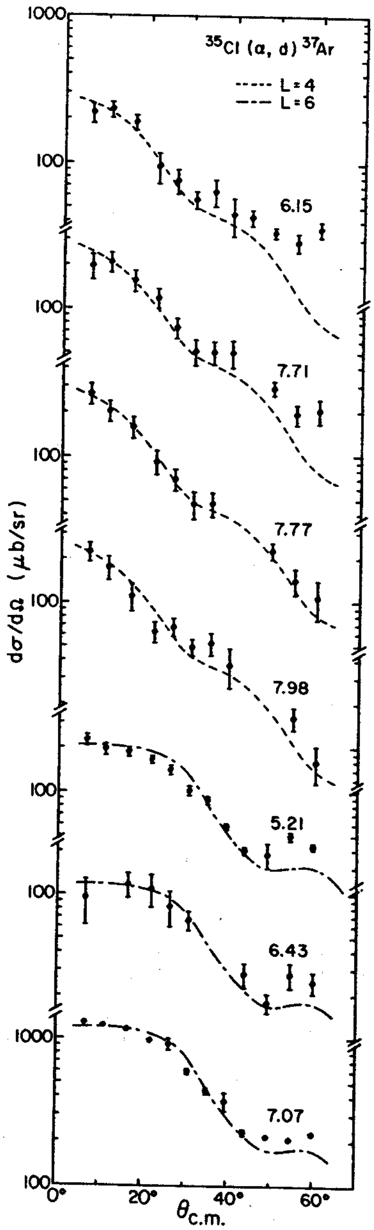

FIG. 1.--L=4 and L=6 angular distribution observed in the $^{35}Cl(\alpha,d)^{37}Ar$ reaction.

The $^{40}Ca(p,t)^{38}Ca$ Reaction

Kamal K. Seth,* A. Saha* and H Nann

We have studied this reaction at E_p=45.245 MeV with an energy resolution, FWHM 12-15 keV in theaangular range =4° to 60°. Forty-four states have been resolved up to an excitation energy of 8 MeV whereas only sixteen were known before.[1,2] J of thirty-four states has been firmly established. This includes seven 0^+, ten 2^+, twelve 3^-, three 4^+ and two 5^- states. An illustration of the quality of the data is provided by Fig. 1 which shows angular distributions of the 0^+ states seen in the present experiment. A paper is in preparation about the nature of these 0^+ states.

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Supported in part by the U.S. Energy Research and Development Administration.

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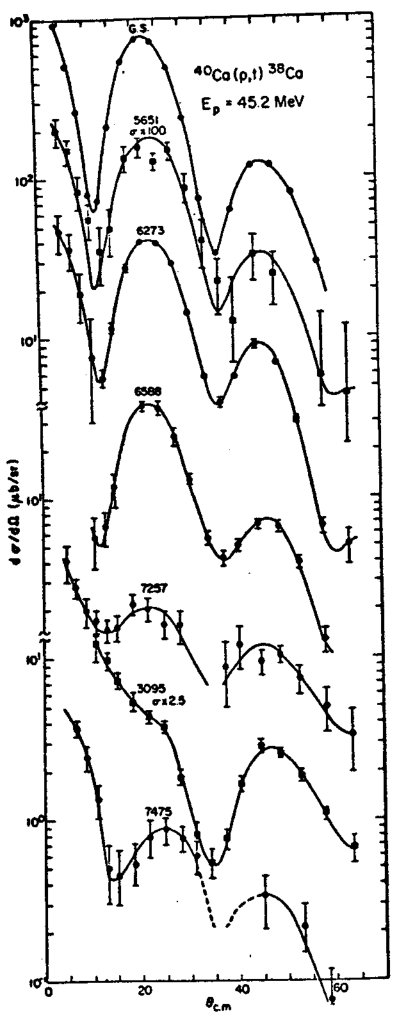

Role of the rms Radius in DWBA Calculations of the (p,d) Reaction

A. Moalem, J. van Hienen, and E. Kashy

Calculations have been carried out for the $^{50,48,46}Ti(p,d)$ reaction at 35 MeV[1] using constant values of the rms radius of the picked-up neutron orbital and adjusting the well depth of the potential to be consistent with the experimental binding energy. Thus the radial form factor had the proper radial dependence of large radii. The values of the rms radii, based upon experimental Coulomb energies, were 4.0 f for $1f_{7/2}$, 3.8 f for $1d_{3/2}$, and 3.9 f for $2s_{1/2}$.

The long standing problem of the Q-dependence of the spectroscopic factors extracted when calculations are compared to data, which is best exemplified by the spectroscopic factors to $T_>$ and $T_<$ levels[1,2] appears essentially met by this method. In addition, better fits to the experimental angular distributions are obtained relative to fits obtained using constant radial geometry for the bound state potential. These results are currently being prepared for publication.

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The Ground State (p,t) Transitions for Calcium Isotopes

Kamal K. Seth,* A. Saha,* and H. Nann

Over the last four years we have studied the (p,t) reaction on calcium isotopes 40, 42, 43 and 48 at E_p=40 MeV.[1] Crawley et al.[2] have studied it on ^{48}Ca. In order to study the systematics of the ground state transitions and in order to understand it in terms of nuclear models, it is necessary to have good relative cross section normalization for the various isotopes. Earlier we had made measurements with a "^{42}Ca target" containing 4.96% ^{40}Ca, 94.42% ^{42}Ca and 0.56% ^{44}Ca, with a "^{43}Ca target" containing 12.78% ^{40}Ca, 5.4% ^{42}Ca and 81.12% ^{43}Ca, and with a "^{44}Ca target" containing 1.40% ^{43}Ca, .006% ^{42}Ca and 98.55% ^{44}Ca. From these targets reasonable relative normalizations (±10%) were obtained only between ^{40}Ca(g.s.) and ^{41}Ca(g.s.) transitions. In order to get one uniform normalization for all isotopes we have studied the (p,t) reaction carefully at E_p=40 MeV, with an overall energy resolution of about 12-15 KeV, at three angles, $\theta_{lab}=18^o$, 20^o and 23^o, using two new targets. The new "^{43}Ca target" contained 12.10% ^{40}Ca, 1.03% ^{42}Ca, 79.9% ^{43}Ca and 6.75% ^{44}Ca according to ORNL mass analysis. The "$ target" was fabricated by mixing equal weights of ^{40}Ca, ^{44}Ca and ^{48}Ca and 'analyzed' as containing 33.5±2.0% ^{40}Ca, 34.1±2.0% ^{44}Ca and 32.4±2.0% ^{48}Ca by measuring elastic scattering of a carbon beam in an angular region where the essentially pure Coulomb scattering from the three isotopes could be clearly resolved.[3] Relative cross sections from these measurements are expected to be accurate to within ±5% and absolute cross sections, which were normalized to our published ^{42}Ca(p,t)^{40}Ca(g.s.) cross sections,[4] are expected to be accurate to within ±10%.

As seen in Table I our cross sections are in excellent agreement with those of Bassani et al.[5] who used 5-10 mg/cm^2 targets which could be weighed quite accurately and for which the authors claim a relative accuracy of ±10% and an absolute accuracy of ±20%. The peak cross section for ^{48}Ca(p,t)^{46}Ca(g.s.) transition reported by Crawley[2] is however 25% higher than ours. The reason for this rather large deviation is not clear.

As has been noted elsewhere the ^{43}Ca(p,t) ^{41}Ca(g.s.) transition has a clear L=2 component.[1,6] At the 22^o peak our best estimate for its contribution is about 17%. After taking account of this, our measured relative L=0 cross sections are as listed in row (f). It is interesting to compare these numbers to model predictions. Bayman and Hintz[5] did this earlier in a mixed configuration ($2s_{1/2}$, $1d_{3/2}$, $1f_{7/2}$, $2p_{3/2}$, $2p_{1/2}$, $1f_{5/2}$) calculation. A much simpler alternative is to compare our results with the pure $(1f_{7/2})^n$ model predictions,[5,7,8] which are: ^{40}Ca(g.s.): ^{41}Ca(g.s.): ^{42}Ca(g.s.): ^{44}Ca(g.s.): ^{46}Ca(g.s.) = 1 : 3/4 : 3/2 : 3/2 : 1. However, since the Q values vary from -11.4 to -8.7 MeV from ^{42}Ca(p,t)^{40}Ca(g.s.) to ^{48}Ca(p,t)^{46}Ca(g.s.) it is necessary to take account of mass and Q-value changes. This is done by performing DWBA calculations. Column (h) in Table I gives the results of such calculations using the optical model parameters due to Nann and Wildenthal[2] in the DWBA code DWUCK. As is seen these $f^n_{7/2}$ model relative cross section predictions are in excellent agreement with our experimental results. This is not to say that our results show that other configurations do not participate; the implication is of essentially an equal amount of participation of the 'non-$f_{7/2}$' configurations in all calcium nuclei. This is completely in agreement with the results of Bayman and Hintz.[5]

TABLE I.--Absolute c.m. cross sections (in μb/sr) for ground state (p,t) transitions at the peak of the second maximum, $\theta_{c.m.} \approx 22^o$.

Target Name \ Target Isotope	40	42	43	44	48
a) "43 target"	350	568	441	743	
b) " $ target "	338			737	337
c) Average of above (±10% absolute, ±5% relative)	344	568	441	740	337
d) Bassani et al. (±20% absolute, ±10% relative)		560		770	355
e) L=0 part of our σ(θ)	344	568	366	740	337
f) L=0 part as fraction of ^{42}Ca	0.59	1.00	0.65	1.30	0.59
g) L=0 'spectroscopic factor' in the pure $f^n_{7/2}$ model		1.00	0.75	1.50	1.0
h) L=0 predicted DWBA relative cross sections		1.00	0.71	1.36	0.71

*Northwestern University, Evanston, IL. Supported in part by the U.S. Energy Research and Development Administration.

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$^{43}Ca(p,t)^{41}Ca$ Re... on

Kamal K. Seth,* A. Saha and H. Nann

The $^{43}Ca(p,t)^{41}Ca$ reaction was studied by us[1] at E_p=40 MeV in 1972 with a 0.5 mgm/cm^2 thick rolled ^{43}Ca target. A single wire proportional counter[2] with about 0.8 to 1.0 mm spatial resolution was used and an overall energy resolution, FWHM≈25 keV was realized. Being the first study of this reaction, several very interesting results were obtained from this investigation. However, the energy resolution was inadequate for the resolution of many interesting states. It was therefore decided to study this reaction once again with better resolution and covering a larger excitation region.

We have studied the reaction with a thin evaporated ^{43}Ca target on a carbon backing with a 'venetian blind' proportional counter[3] which has a factor two better spatial resolution capability. Fig. 1 shows a typical triton spectrum obtained in the present experiment. Notice an almost total absence of background up to 11 MeV excitation and the excellent energy resolution (FWHM=12 keV) permitting the resolution of previously unresolved states, e.g., the 2575 keV and 2605 keV doublet.

Data was taken between 6° and 55° and is being presently analyzed for angular distributions.

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Supported in part by the U.S. Energy Research and Development Administration.

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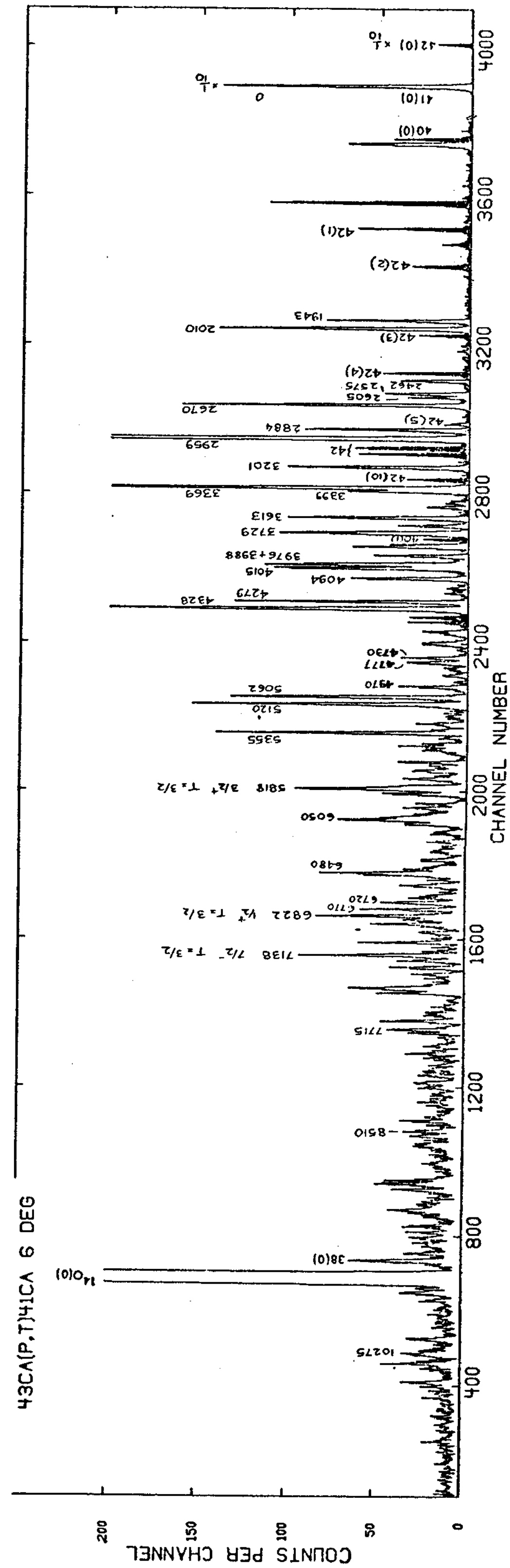

FIG. 1.--Triton spectrum from the $^{43}Ca(p,t)^{41}Ca$ reaction.

The $^{59}Ni(p,t)^{57}Ni$ Reaction

H. Nann, A. Saha, and S. Raman*

The $^{59}Ni(p,t)^{57}Ni$ reaction has been studied at 40 MeV bombarding energy. The target consisted of reactor produced ^{59}Ni (enriched to about 99%) on a carbon backing and was about 50 $\mu g/cm^2$ thick. The tritons were momentum analyzed in an Enge split-pole spectrograph and detected in the focal plane by a position sensitive proportional counter with delay line readout backed by a plastic scintillator. A typical spectrum is shown in Fig. 1. The energy resolution obtained was about 15 keV (FWHM). Many new levels of ^{57}Ni were observed.

Angular distributions have been measured from 6^o to 55^o. From the shapes of the angular distributions, values of the transferred orbital angular momentum L have been extracted. Predominant L=0 angular distributions were observed for the transitions to the g.s., 3.01, 4.92, and 5.19 MeV states in ^{57}Ni. This allows to assign for these states the unique spin and parity value $J^\pi=3/2^-$. The transitions to the levels at 1.11 $(1/2^-)$, 2.58 $(7/2^-)$; 3.23 (7.2^-), 3.37, 4.58, and 5.24 $(7/2^-)$ MeV show predominant L=2 angular distributions. The levels at 0.77 $(5/2^-)$, 2.44 $(5/2^-)$, 3.86, 3.88, 4.07, 4.23, 4.37, and 7.13 MeV are excited by predominant L=4 angular distributions. In all these transitions the patterns of the other L values which are allowed by the selection rules are visible but weak.

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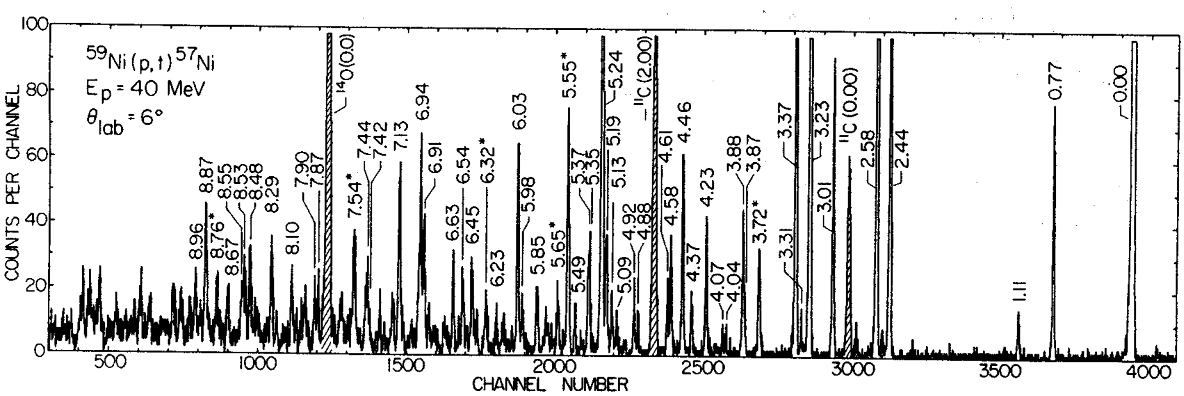

FIG. 1.--Triton spectrum from the $^{59}Ni(p,t)^{57}Ni$ reaction.

A Study of States in ^{66}Ge

R.C. Pardo, L. Young and Aaron Galonsky

The zinc isotopes have recently been the subject of intense shell model study.[1] It is felt[2] that the techniques used there can be extended -- at least into the lighter germanium isotopes. In other studies of nuclei in this region, data interpretation using collective models has been fruitful. Therefore, an extensive understanding of nuclei in the region just past the $f_{7/2}$ shell closure may give valuable information concerning the interplay between particle and collective properties and concerning the relationship between parameters used in the two descriptions.

Recent experiments on the germanium isotopes have included (p,t) reactions, γ-rays following heavy ion reactions, and β-decay. References 3-5 are examples of some relevant work on the light germanium isotopes. Present knowledge of the lightest germanium nuclei (^{64}Ge-^{66}Ge) consists of only a few levels observed in ^{66}Ge cited in Ref.4. We have undertaken a study of ^{66}Ge using the ^{64}Zn(^{3}He,n)^{66}Ge reaction at $E_{^3He}$ = 19 MeV. The major aim of the present work is to assign spin and parity quantum numbers to the states observed. This would also provide a basis for additional work, such as γ-ray studies following heavy-ion reactions.

The present experiment is being performed with the neutron time-of-flight apparatus. Preliminary spectra taken indicate an initial resolution of $\gtrsim$250 keV FWHM at a 7.3 m flight path. It is our hope that the beam characteristics will be sufficiently improved that a resolution of 100-150 keV can be obtained by using a longer flight path and better beam bunching techniques. Although much work lies ahead, initial results are encouraging, and additional experiments are in progress.

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Study of the ^{104}Cd Nucleus Through the ^{106}Cd(p,t)^{104}Cd Reaction at E_p= 42 MeV

B. Zwieglinski, G.M. Crawley and W. Benenson

The high-spin states of the neutron-deficient d and Pd nuclei have been recently the subject f an intense study via (α,xn) reactions. The rimary motivation for the present ^{106}Cd(p,t)^{104}Cd xperiment was to get an information on the ow-spin states in ^{104}Cd as excited by the two-eutron pick-up reaction. A contribution of he two-step transfer process was found for he transitions to the 2_1^+ states in the (p,t) eactions on the even Pd nuclei.[1] This contribu-ion was found to interfere destructively with he main direct transfer process. It is interest-ng to investigate whether similar effects occur or the even-even Cd nuclei and for states other han 2_1^+.

The ^{106}Cd(p,t)^{104}Cd reaction has been studied t the proton energy of 42 MeV with a 1.0 mg/cm^2 arget enriched to 82% in ^{106}Cd. Triton spectra ave been measured with a position-sensitive roportional counter at the focal-plane of the plit-pole magnetic spectrograph. The spectrum easured at the laboratory angle of 8^o is shown n Fig. 1. The resolution is about 40 keV. ne states of ^{104}Cd at 0.0, 0.663, 1.482, 1.755, .099, 2.411, 2.451, 2.556, 2.618, (2.829), .889, 2.991 and 3.224 MeV are observed in the resent experiment. The angular distributions or the strongest lines in the spectrum are resented in Fig. 2. The group at 1.482 MeV orresponds to a member of the "two-phonon" riplet. A rather featureless angular distri-ution may suggest that this peak is composite. ne systematics of the octupole states in this ss region indicates that the strongly excited 8^o (see Fig. 1) 2.099 MeV group corresponds the 3$^-$ state.

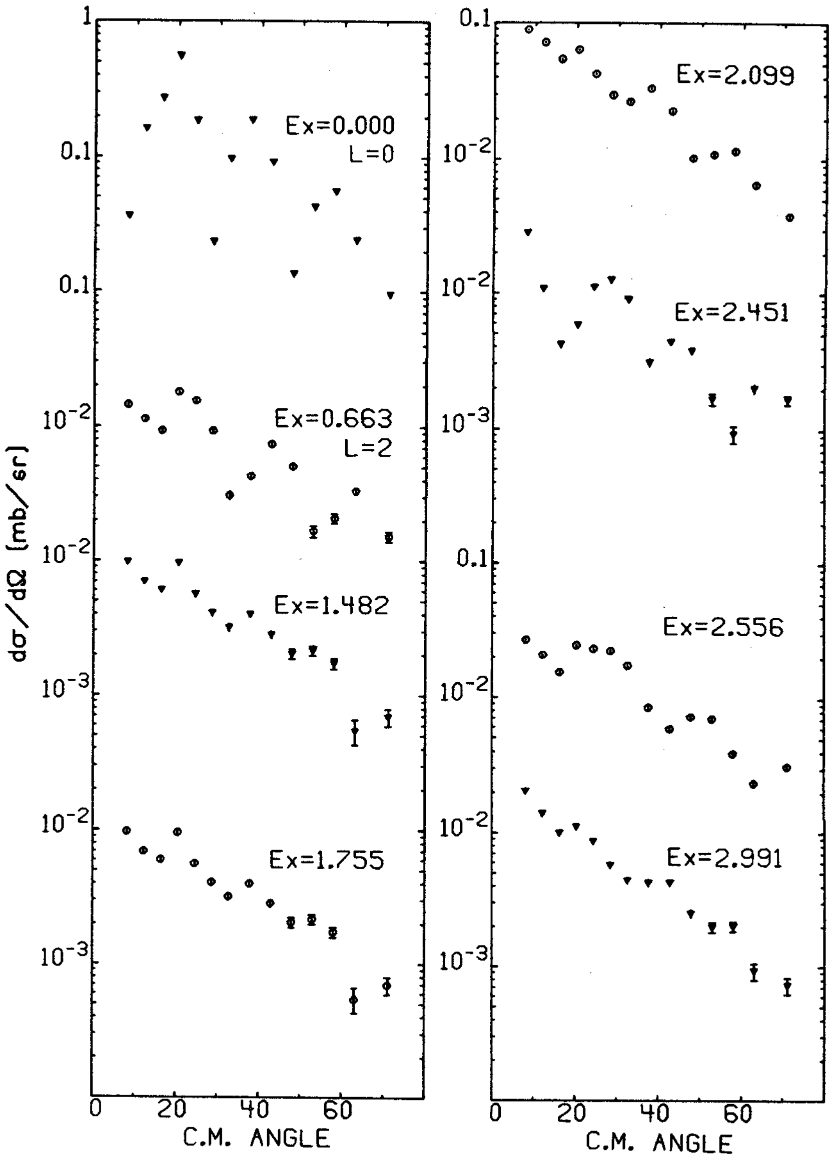
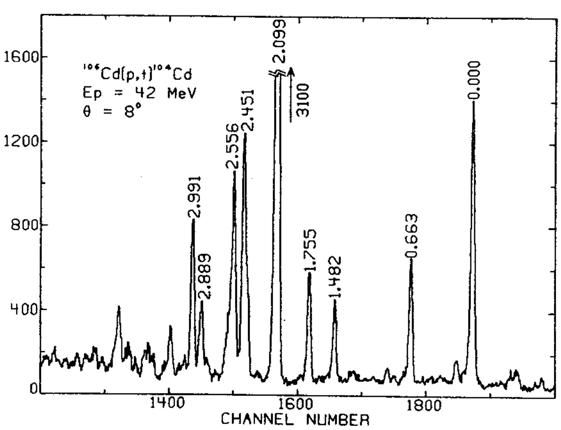


FIG. 2.--Differential cross sections for the ^{106}Cd(p,t)^{104}Cd reaction at E_p=42 MeV.



G. 1.--Spectrum of tritons from the ^{106}Cd(p,t)^{104}Cd action at the proton energy E_p=42 MeV and e laboratory angle of 8^o.

Prior to the quantitative analysis of the data we plan to perform an additional experiment with a resolution better than 10 keV in order to decide which of the peaks are composite.

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Study of the (p,t) Reaction on ^{194}Pt, ^{196}Pt and ^{198}Pt

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

The isotopes of W, Os, and Pt lie in a transitional region of nuclei, between well deformed rare-earths and the spherical nuclei near the doubly magic ^{208}Pb. There has been an increase in interest in recent years in these nuclei in an effort to understand their structure and to determine the slowly-changing shape characteristics through this region. It has been known for several years that a transition from a prolate to oblate shape occurs between the heavier Os and the lighter mass Pt nuclides, with the latter found to be oblate.[1] Attempts to explain the level structure in terms of a simple vibrator or symmetric rotor have not been very successful, primarily due to the apparent lack of a candidate for the 0^+ member of the 2-phonon triplet. However recent evidence suggests that some aspects of the odd platinum nuclei can be explained in terms of a triaxial rotor.[2] Several other models have been applied in this region with varying success.[3]

Since knowledge of low-lying 0^+ states is essential in distinguishing many of the various models, a search for 0^+ states below 1 MeV in excitation was undertaken using the (p,t) reaction on three even platinum isotopes, ^{194,196,198}Pt. The distinctive shape for L=0 transfers in two-nucleon transfer reactions was used for identification of 0^+ states in the residual nucleus.

We have measured the angular distributions of the ^{194,196,198}Pt(p,t) reactions with E_p=35 MeV, for most levels below 2.5 MeV in excitation (see Fig. 1). The triton spectra were recorded using a delay-line, position-sensitive proportional counter[4] placed in the focal plane of the Enge split-pole spectrograph. The resolution obtained was ~15 keV using rolled-foil targets with a thickness of 600 μg/cm^2. In addition, tritons were detected in photographic emulsions at three angles for each nuclide with a resolution of 6-7 keV FWHM, using thin (150 μg/cm^2) sputtered targets.

We have found no evidence for any new levels below 1.5 MeV in all three Pt isotopes studied: ^{192,194,196}Pt. We can set an upper limit on the cross section for populating any 0^+ state at 1.0 μb/sr, assuming the L=0 transfers retain their present shape as seen for all Q-values. Angular distributions for L>0 also are sometimes sufficiently characteristic to permit L-value assignments, the main exceptions being the first 4^+ in all three residual nuclei. Overall the data exhibit a close resemblance to DWUCK72[5] calculations and (p,t) data for the lead isotopes.[6] These shape characteristics were not seen in the Os(p,t) study at 19 MeV.[7] This feature has allowed us to make several tentative J^π assignments in ^{192,194,196}Pt. An interesting new level seen in all three nuclei at ~1.9 MeV excitation has been identified as a 4^+ state based on the shape of its angular distribution. Two of these L=4 transfers are quite strong with only the cross section into the ground state and first 2^+ surpassing them.

One method for obtaining spectroscopic information from two-nucleon transfer cross sections with DWBA calculations is to use an empirical normalization for D_o^2 and define an enhancement factor[8] for the strongest configuration for a given L transfer.[9] Table I lists ε values for several levels studied in this work. Note that the 4^+ state at ~1.9 MeV in ^{194,196}Pt shows an enhancement on the order of the ground state. The only other transitions showing this enhancement are the first 2^+ in ^{196}Pt and two high L-transfers (6 or 7) in ^{194,196}Pt. We are continuing their study further with inelastic proton scattering (see elsewhere in this Annual Report).

Table I. Table of enhancement factors for several transitions seen in the ^{194,196,198}Pt(p,t) reactions.

Reaction	E(MeV)	L	ε*
^{194}Pt(p,t)^{192}Pt	0.0	0	5.6
	1.195	0	.08
	1.628	0	.28
	0.316	2	.91
	0.613	2	.17
	0.785	4	.23
	1.937	4	.35
^{196}Pt(p,t)^{194}Pt	0.0	0	3.9
	1.267	0	.09
	1.479	0	.03
	1.547	0	.28
	0.328	2	1.4
	0.622	2	.17
	0.811	4	.11
	1.229	4	.68
	1.911	4	2.1
	1.990	(6,7)	(.99,3.87)
^{198}Pt(p,t)^{196}Pt	0.0	0	3.9
	1.135	0	.12
	1.402	0	.16
	1.824	0	.34
	0.355	2	2.37
	0.690	2	.13
	0.877	4	.13
	1.884	4	2.2
	2.296	(7)	2.6

*Configurations used in DWBA calculations; $(2p_{1/2})^2$ for L=0, $(2p_{3/2} \otimes 1f_{7/2})$ for L=2, $(1f_{5/2} \otimes 2p_{3/2})$ for L=4, $(1f_{5/5} \otimes 1f_{7/2})$ for L=6 and $(2p_{1/2} \otimes 0i_{13/2})$ for L=7.

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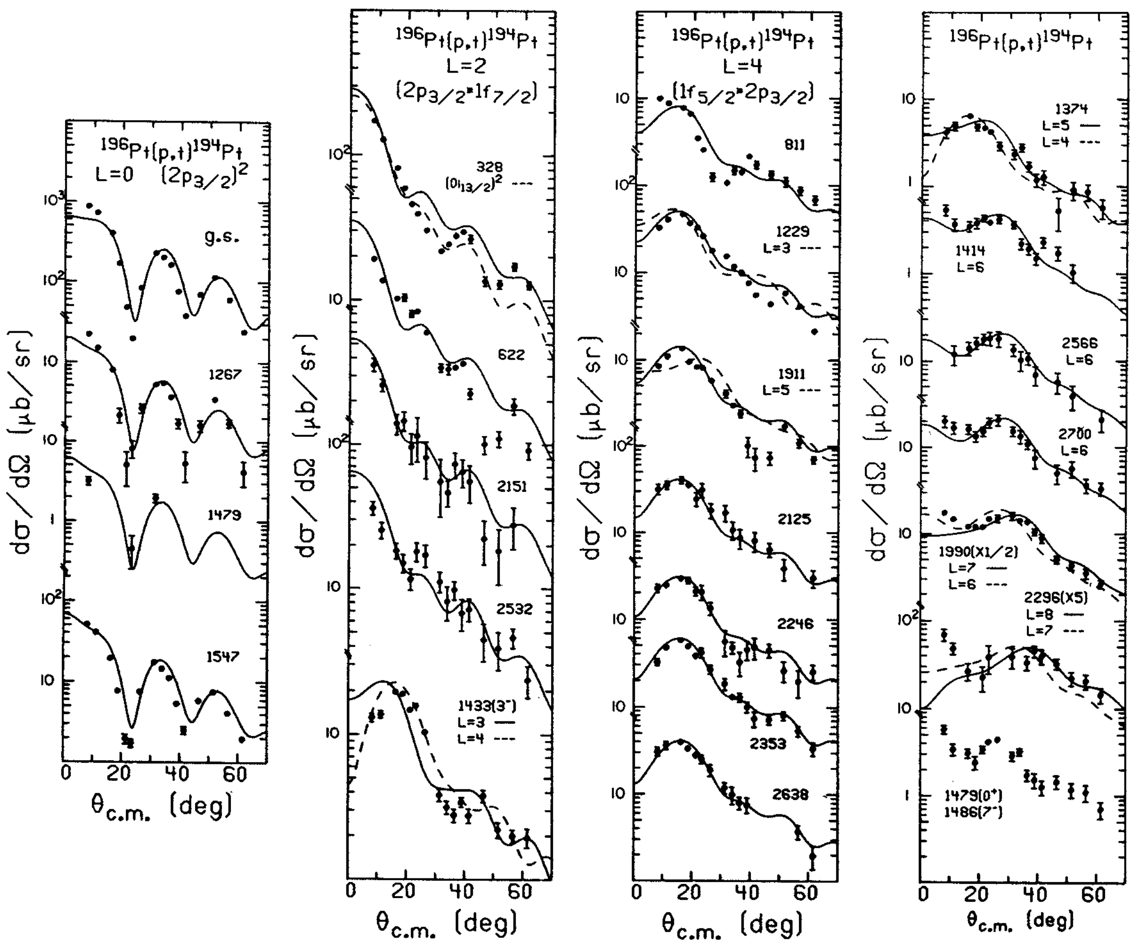

FIG. 1.--Angular distributions for various levels populated in the ^{196}Pt(p,t) reaction.

A Study of $^{208}Pb(p,\alpha)$

P.A. Smith, D. Weber, G.M. Crawley and R.G. Markham

The nuclei near the doubly magic ^{208}Pb nucleus are important to our understanding of nuclear phenomena, since the spectra of these nuclei should be explainable through the consideration of simple excitation modes such as single particle or collective excitations. The nuclei which differ from ^{208}Pb by one particle have been extensively studied with direct single nucleon transfer reactions, while the two nucleon transfer reactions have received less attention owing to greater experimental difficulties and more complicated analysis. The nuclei which are three quasiparticles removed from the Z=82, N=128 core are especially important since their spectra represent the coupling of the odd nucleon to the spectrum of two quasiparticle states. Thus, these spectra are particularly amenable to empirical shell model calculations, where the two body interactions are determined from the two quasiparticle spectra, or to weak and intermediate coupling models. Shell model calculations have been carried out at Copenhagen for a number of these nuclei with outstanding agreement for the high spin states, which they have located by $(\alpha,xn\gamma)$ reactions. Unfortunately ^{205}Tl, which should be one of the easiest nuclei to analyze in terms of a shell model scheme since it can be considered as a three hole spectrum, is difficult to reach with fusion-evaporation reactions.

We have studied the $^{208}Pb(p,\alpha)^{205}Tl$ reaction at 35 MeV with the hope of identifying some of the high spin states that can be made from coupling a proton hole to an $(i_{13/2})^{-2}$ neutron configuration. Furthermore, a recent publication on the $(\vec{t},\alpha)$ reaction on the lead isotopes has elucidated how the $s_{1/2}, d_{3/2}, d_{5/2}$, and $h_{11/2}$ proton hole strengths are distributed in ^{205}Tl. A comparison of the $^{208}Pb(p,\alpha)^{205}Tl$ spectra and the $(\vec{t},\alpha)$ results can help to clear up some of the ambiguous assignments made in that work. We therefore have carried out a qualitative analysis of coherence, j-dependence, and DWBA calculations for the $^{208}Pb(p,\alpha)^{205}Tl$ reaction.

The target was made by evaporating 40 $\mu g/cm^2$ of enriched ^{208}Pb onto a 20 $\mu g/cm^2$ carbon backing. The target thickness was determined by comparing elastic proton scattering to an optical model calculation. The reaction products were analyzed with an Enge split-pole spectrograph and detected with the Markham-Robertson delay line counter in the focal plane. The α-particles were identified by their energy loss in the counter and by their time-of-flight relative to the cyclotron radio frequency. Two typical spectra obtained with this system are shown in Fig. 1. The energy resolution is about 20 keV FWHM.

Evident features of the data are the extreme forward peaking of the low lying states and the emergence of the large peak in the large angle spectrum. Because of the former, the ground state is nearly invisible in the lower portion of Fig. 1. The large peak in the 40° spectrum is clear evidence for a high spin assignment.

Our (p,α) spectra are not similar to the $(\vec{t},\alpha)$ results. For example, the $7/2^+$ state at .920 MeV excitation is strongly populated in the (p,α) spectra of Fig. 1 but is at least 2 MeV below the lowest possible fragments of the $g_{7/2}$ hole found in the $^{206}Pb(\vec{t},\alpha)^{205}Tl$ experiment.

Some sample angular distributions are given in Fig. 2. The curves are the results of DWBA calculations using mass-3 cluster form factors. There appears to be very little j-dependence, the primary feature being strong forward peaking for all angular momentum transfers <4. The angular distribution for the high spin state mentioned previously appears to be fit best with the ℓ=10 calculation.

The analysis of this reaction is nearly complete. We hope to be reporting all the results in the near future.

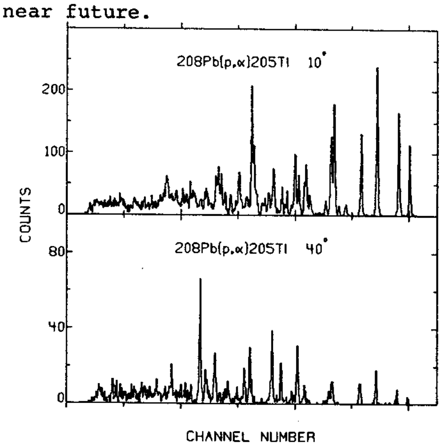

Fig. 1.—Spectra taken at 10° and 40°.

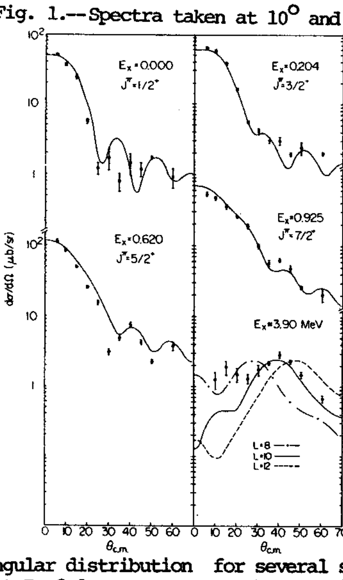

Fig. 2.—Angular distribution for several states in ^{205}Tl. The state at E_x~3.9 MeV appears to have a high spin and is the prominent peak in the 40° spectrum of Fig. 1.