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Level Structure of ^{92}Mo and ^{94}Mo Studied with the (p, t) Reaction*

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The ^{94}Mo$(p,t)^{92}$Mo and ^{96}Mo$(p,t)^{94}$Mo reactions have been studied at an incident proton energy of 31 MeV. The triton spectra were obtained with a magnetic spectrograph with over-all resolution of about 20 keV. Experimental angular distributions are compared with two-nucleon-transfer distorted-wave Born-approximation calculations to extract spin-parity assignments and enhancement factors. Particular emphasis is placed on the study of the $L=0$ transitions near the closed shell at 50 neutrons.

I. INTRODUCTION

This paper reports on the energy levels of ^{92}Mo and ^{94}Mo observed by means of the two-neutron-transfer (p, t) reaction. The principal motivation for this work was to obtain two-nucleon-transfer data on the molybdenum isotopes to complement previous studies of the (p, t) reaction on the zirconium isotopes.[1,2] Of particular interest was the identification of the 0^+ states in these nuclei and the study of the $L=0$ transfer intensity systematics near the $N=50$ closed neutron shell.

One of the most interesting results from the previous zirconium (p, t) study was the observation that the ground-state transition from the $N=50$ nucleus ^{90}Zr was a highly correlated $L=0$ transfer that exhausted almost all of the strength expected for removal of zero-coupled neutron pairs from the orbitals comprising the closed major shell. This same correlated core-pickup state, if observed, in the heavier zirconium isotopes would correspond to an excited 0^+ level. One description of such a state is that of a "pairing vibration."[3] In the zirconium isotopes it was observed[2] that this expected core-pickup state, or pairing vibration, was fragmented and summed to less intensity than expected. In the molybdenum study reported here, we present results on the effect of two additional protons on the pairing-vibration properties of nuclei near $N=50$. In addition, results on levels observed with $L>0$ transfer are also reported.

The present study was performed at a proton energy of 31 MeV, since we had observed previously that the angular distributions for different L transfers are more distinct at this energy[1] than at higher proton energies (e.g., 38 MeV).[2] During the course of this work, a number of other investigations of molybdenum (p, t) reactions, covering some aspects of interest here, have been reported.[4-7] These experiments were all performed at higher proton energies with reported resolutions typically 4–5 times poorer than the present work. Where these previous studies overlap the present results, appropriate comparisons will be made.

II. EXPERIMENTAL RESULTS

The reactions were studied with 31-MeV protons from the Oak Ridge isochronous cyclotron. The targets were rolled, self-supported foils of isotopically enriched molybdenum metal. The thicknesses and isotopic abundances of the targets are given in Table I. Tritons were detected by nuclear emulsions in the broad-range magnetic spectrograph facility with a typical over-all resolution of 20 keV full width at half maximum.

At the time the present study was initiated, a preliminary report of the ^{92}Mo(p, t) reaction studied with 40-MeV protons had been received.[4] Subsequently, a more complete study of this same reaction with 39-MeV protons has been reported.[7] We have, therefore, restudied this reaction only over a limited angular range sufficient to extract the ground-state $L=0$ transition intensity at 31 MeV. These data are included in the discussion of the $L=0$ transfer systematics in Sec. IV A. No data for excited states in the ^{92}Mo$(p, t)^{90}$Mo reaction were analyzed in the present study.

An example of the spectra obtained for the ^{94}Mo$(p, t)^{92}$Mo reaction is shown in Fig. 1 and for the ^{96}Mo$(p, t)^{94}$Mo reaction in Fig. 2. The choice of 31-MeV proton energy was based on the desire to increase the distinction between angular distributions for different L-transfer values. In particular, at this energy, the $L=0$ transfer has the dis-

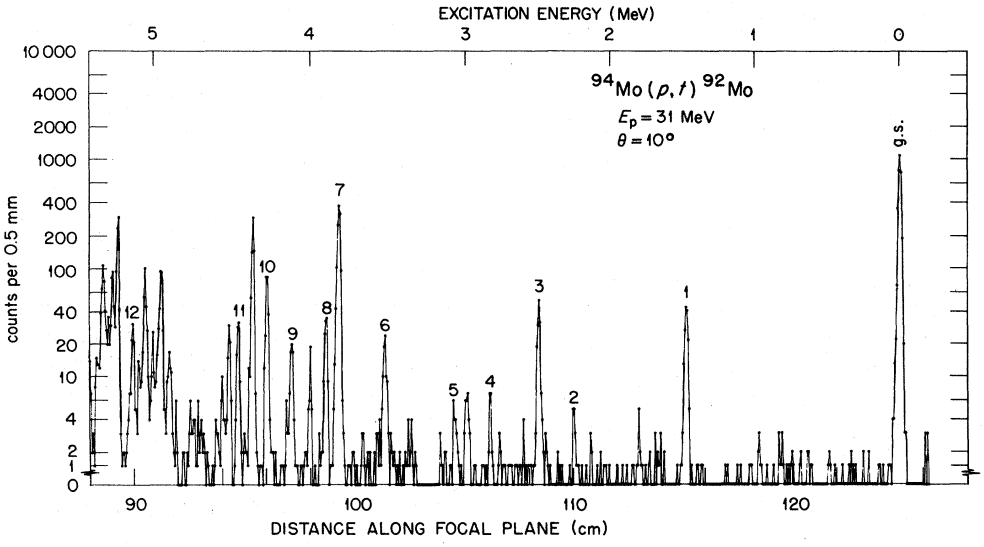

FIG. 1. Energy spectra of tritons observed at 10° from the interaction of 31-MeV protons with ^{94}Mo.

tinct signature of a sharp rise at forward angles. One adverse effect of this low an incident energy is that deuterons from the (p, d) reactions on the molybdenum isotopes begin to overlap the triton spectra in the region of 5 MeV of excitation. The presence of these deuteron groups and the high level density of triton groups precludes any detailed analysis of levels above 5.5 MeV of excitation, even with the present 20-keV resolution.

The main source of error in the cross sections determined in this work arises from uncertainties in target thickness. Thicknesses determined by comparison of measured elastic scattering yields to those predicted with the optical-model parameters of the next section agreed to within 10% with thicknesses obtained by weighing. Since the optical parameters for proton scattering are well determined in this energy region, they are expected to reproduce the measured cross sections within a few percent. The thicknesses determined from the scattering were used to compute the (p, t) cross sections, since they should partially cancel possible systematic errors. Using either method, relative cross sections are estimated to be accur-

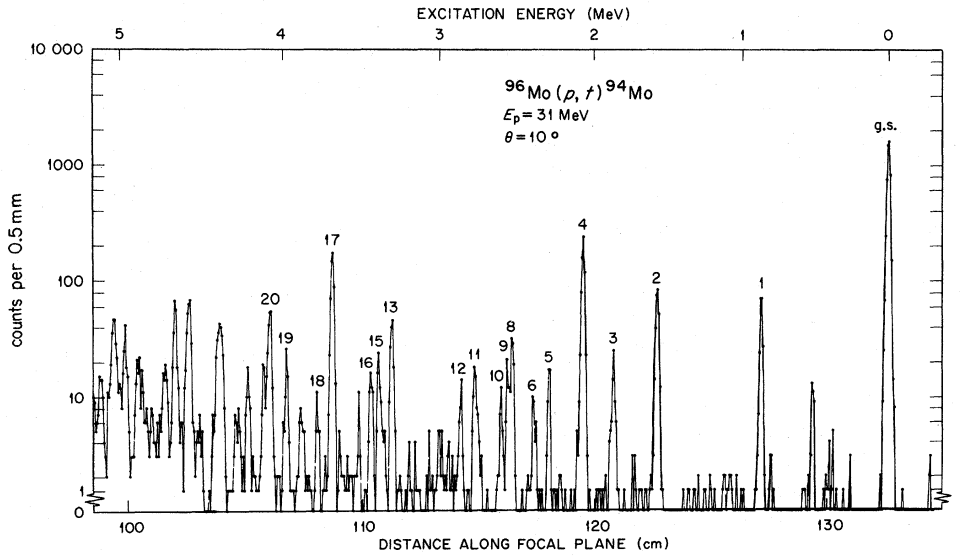

FIG. 2. Energy spectra of tritons observed at 10° from the interaction of 31-MeV protons with ^{96}Mo.

ate to 3–4%, while absolute cross sections carry an uncertainty of 10%.

III. DWBA ANALYSIS

Angular distributions from the triton groups from the ^{94}Mo(p, t) and ^{96}Mo(p, t) reactions are shown in Figs. 3 and 4, respectively. The solid lines are the results of zero-range, two-nucleon-transfer, distorted-wave Born-approximation (DWBA) calculations performed with the computer program JULIE.[8]

The relationship of the output of the JULIE program to the experimental cross section has been discussed in detail previously.[2] For the purpose of this paper we will abbreviate the more complicated expression to the form

$$\sigma_{\text{exp}}(\theta) = 2D_0^2 \mathcal{E} \left| \sum_{j_1 j_2} B(j_1 j_2 J)\, \tilde{\beta}_{\text{JULIE}}(j_1 j_2 J, \theta) \right|^2 ,$$

where D_0^2 is the normalization factor which arises from the zero-range approximation, B is the two-particle spectroscopic amplitude for the particular configuration considered, $\tilde{\beta}$ is the transition amplitude computed by the code JULIE, and $\mathcal{E}$ is the "enhancement factor" which provides a comparison of predicted and measured transition intensities. Deviations of the enhancement factors from unity should thus indicate deficiencies in the wave functions assumed for the DWBA calculations. In most cases, since complete wave functions are not available, DWBA calculations are performed assuming a simple, single shell-model configuration that might be expected to contribute significantly to the particular transition. (In this case there is then no sum over $j_1 j_2$ pairs.) Future comparison of the predictions of complex wave functions can then be made simply by calculating the predicted enhancements with respect to the simple configurations and comparing these with the experimental enhancements.

The single-particle wave functions for the transferred neutrons were calculated for a Woods-Saxon well by the oscillator wave-function expansion method of Drisko and Rybicki.[9] The real-well-radius parameter of the Woods-Saxon potential was $r_0 = 1.25$ fm and the diffusivity was $a = 0.65$ fm. A Thomas-type spin-orbit term was included with this same geometry and a strength $\lambda = 25$. The single-neutron binding energies were chosen as one half of the two-neutron separation energy required to reach the final state involved.

The optical-model parameters used for the DWBA calculations are given in Table II. The proton parameters are taken from the global analysis of Becchetti and Greenlees.[10] This is the same parameter set as used in a previous analysis of the zirconium (p, t) data.[2] Two sets of triton parameters were employed and both are listed in Table II. The parameter set taken from the analysis of Drisko, Roos, and Bassel[11] is the same as that used previously for the zirconium data. The second set of triton parameters, taken from the work of Flynn *et al.*,[12] has had more general use and was included here for comparison. The two sets of triton parameters yield essentially identical shapes for the predicted angular distributions but result in significantly different magnitudes.

A comparison of DWBA predictions using the two sets of triton parameters from Table II shows that the cross sections predicted using the parameters of Drisko, Roos, and Bassel are consistently 30% larger than those obtained using the parameters of Flynn *et al.* This difference will thus require a different value of D_0^2 to obtain consistent enhancement factors from the two parameter sets. We have included those two sets in Table II to call attention to the difficulties attendant to absolute normalization of two-nucleon-transfer calculations. We have pointed out previously[2] that relatively small changes in the bound-state geometry (changing r_0 from 1.25 to 1.20 fm) also result in quite dramatic changes in predicted cross sections.

The data on the energy levels observed in ^{92}Mo and ^{94}Mo are summarized in Tables III and IV. Enhancement factors, extracted for the simple configurations listed, are included in the tables. For the triton parameters of Drisko, Roos, and Bassel, a value of $D_0^2 = 22$ was used in the present analysis to be consistent with the previous analysis of the Zr(p, t) reactions.[2] The same results are obtained from calculations using the triton parameters of Flynn *et al.* with a value of $D_0^2 = 29$.

TABLE I. Nominal target thicknesses and isotopic abundances.

Target	Thicknesses (mg/cm^2)	^{92}Mo	^{94}Mo	^{95}Mo	^{96}Mo	^{97}Mo	^{98}Mo	^{100}Mo
^{92}Mo	0.56	98.27	0.46	0.37	0.26	0.13	0.27	0.25
^{94}Mo	0.37	0.87	93.6	2.85	1.04	0.40	0.75	0.22
^{96}Mo	0.43	0.18	0.18	0.94	96.8	0.96	0.82	0.1

IV. DISCUSSION

A. $L = 0$ Transitions

The relative (p, t) intensities observed for $L = 0$ transitions are summarized in Fig. 5. This figure also includes the ground-state transition intensity measured in the ^{92}Mo$(p, t)^{90}$Mo reaction. Since none of the previous studies[4,7] of this reaction have reported any appreciable $L = 0$ strength to excited 0^+ levels in ^{90}Mo, this intensity would seem to represent the bulk of the strength expected for removal of zero-coupled neutron pairs from the $N = 50$ shell. The enhancement factor extracted by assuming pure $(g_{9/2})^2_0$ pickup is 7.0, significantly less than the factor of 10.0 obtained for the similar transition from ^{90}Zr.

From a simple shell-model viewpoint, the proton structure of the molybdenum nuclei can be ascribed to filling of the $2p_{1/2}$ and $1g_{9/2}$ orbitals beyond an inert ^{88}Sr core. In such a model, the ground state of ^{92}Mo will be of the form

$$\alpha(\pi p_{1/2})^2_0(\pi g_{9/2})^2_0 + \beta(\pi g_{9/2})^4_0 ,$$

and the orthogonal combination will result in a low-lying 0^+ excited state. If the configuration mixture of the protons is unaffected as neutrons are added beyond the $N = 50$ core, such 0^+ states would not be populated by the (p, t) reaction. In the case of the zirconium isotopes, a weakly pop-

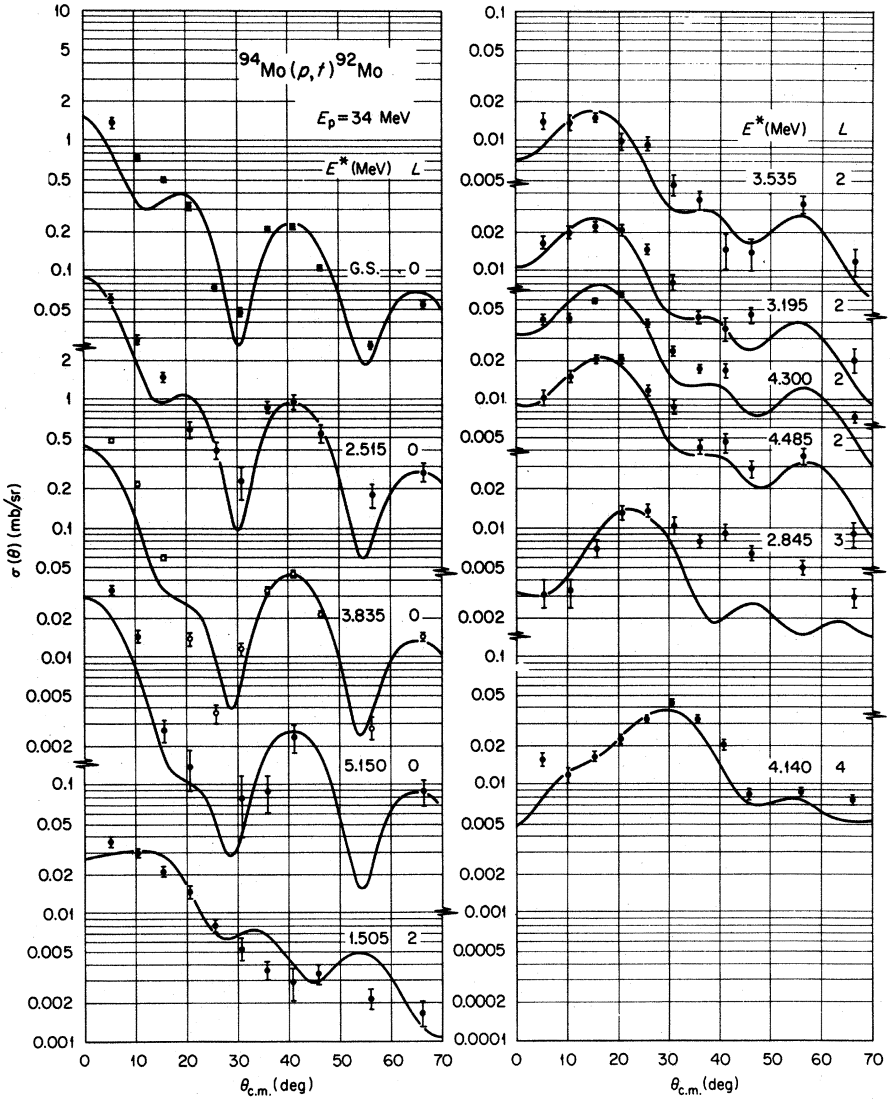

FIG. 3. Angular distributions for the triton groups observed in the ^{94}Mo$(p, t)^{92}$Mo reaction. The curves are results of DWBA calculations for the indicated L-transfer values.

ulated 0^+ excited state was observed in all the even isotopes with $N \geq 50$, indicating the presence of some configuration changes.[13] The observed intensities were shown to be consistent with the changes in proton structure deduced from results of single-proton-transfer experiments.

One of the initial motivations for the present study was to locate a low-lying excited 0^+ level in ^{92}Mo that might be ascribed to the expected proton excited state. The level at 2.515 MeV of excitation seems to be an excellent candidate for this state, since it is reasonably close in energy to the predicted position[14,15] for such a level and is rather weakly populated as expected. This 0^+ level has also been reported recently in studies of this same reaction at higher energies.[5,6] Unlike the case for the zirconium isotopes, we do not see this low-lying proton excited 0^+ level in the $N = 52$

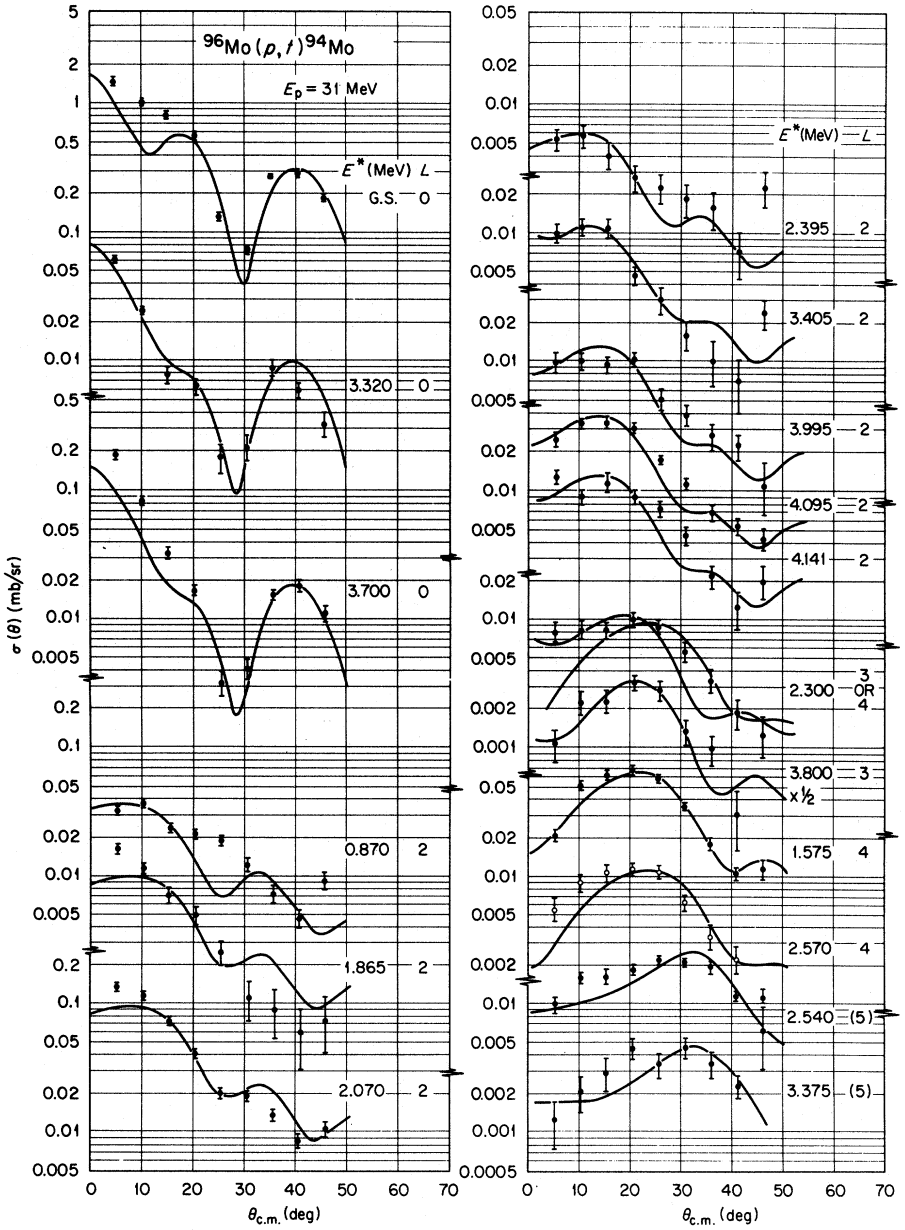

FIG. 4. Angular distributions for the triton groups observed in the ^{96}Mo$(p, t)^{94}$Mo reaction. The curves are results of DWBA calculations for the indicated L-transfer values. (It should be noted that there are significant shifts in the angular structure with changing Q value.)

nucleus, ^{94}Mo. This suggests that the proton structure of ^{94}Mo and ^{96}Mo is remarkably similar.

The higher-lying 0^+ states observed in ^{92}Mo are assumed to arise from removal of neutron pairs from the $N=50$ core and hence correspond to the pairing-vibration excitation in this nucleus. Although a very weakly populated level is observed at 5.15 MeV, quite close to the energy expected for the pairing vibration from the simple harmonic form of the model, the bulk of the intensity is observed to populate a 0^+ level more than 1 MeV lower in excitation. The pairing-vibration intensity observed in ^{92}Mo is only 55% of the ground-state transition from ^{92}Mo to ^{90}Mo. In the zirconium isotope (two protons less) this ratio was found to be about 75%. Thus both the energy shift and intensity loss of the pairing-vibration strength are more pronounced in molybdenum than zirconium and more closely resemble the behavior of such states observed previously in the neodymium isotopes.[16]

The results for the 0^+ levels in ^{92}Mo are very similar to the results reported[5] at a bombarding energy of 40 MeV, but the intensity ratios are noticeably different from the 52-MeV results.[6] Neither of the previous experiments observed the 0^+ level at 5.15 MeV.

In the ^{96}Mo(p, t) reaction we observe two excited 0^+ levels. Only the stronger of these, at 3.70 MeV, has been reported previously.[6] We have examined the spectra for this reaction up to about 5.5 MeV of excitation and observe no other $L=0$ transitions of comparable intensity. These results thus parallel rather closely the previous results on the zirconium and neodymium isotopes in that the pairing-vibration strength is fractionated and diminished in intensity as neutrons are added beyond the closed shell. Except for the neutron closed-shell nucleus, no single state is observed to carry the bulk of the expected pairing-vibration strength.

B. Levels in ^{92}Mo

The properties of the ^{92}Mo levels summarized in Table III are generally in good agreement with those reported[5] from the same reaction at a proton energy of 40 MeV. We prefer a 2^+ assignment for the 3.535-MeV level rather than the tentative 3^- assigned previously. The level observed here at 5.150 MeV is quite definitely a 0^+ state. We do not observe the 4^+ level reported previously[5] at 5.09 MeV, but this region is difficult to analyze because of interfering deuteron groups.

The enhancement factor of 1.5 for the ^{94}Mo(p, t)-^{92}Mo ground-state transition is slightly less than the enhancement for the analogous transition in the zirconium isotopes.[2] The rather strong transition to the first excited 2^+ level, presumably a state due primarily to proton excitation, should be noted. The enhancement factor for this state is about twice that for the similar state in the ^{92}Zr$(p, t)^{90}$Zr reaction. This does not necessarily imply that there are neutron components in these 2^+ levels but, more likely, that the ground-state wave functions for the $N=52$ nuclei contain significant components with these 2^+ states coupled to $\nu=2$ neutron configurations. The present results then indicate significantly more mixing in the wave functions for the molybdenum case than for the zirconium case.

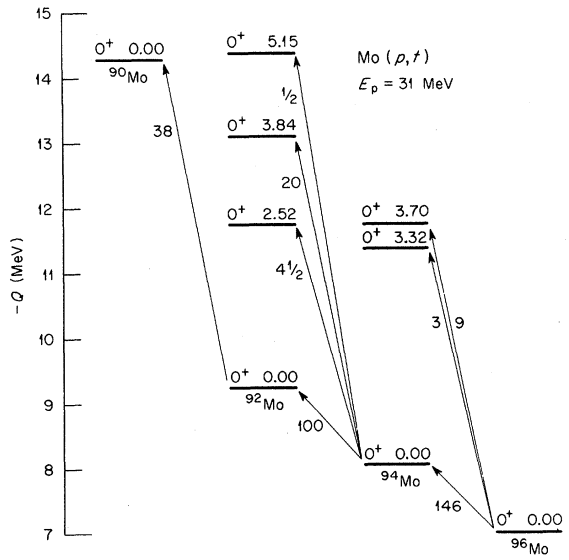

FIG. 5. Relative $L=0$, (p, t) transition intensities.

TABLE II. Optical-model parameters used in the DWBA calculations. The notation for the parameters is the same as that of Satchler [see G. R. Satchler, Nucl. Phys. A92, 273 (1967)]. Multiple values are for ^{92,94,96}Mo, respectively.

	Protons	Tritons [a]	Tritons [b]
V (MeV)	54.7, 55.1, 55.5	170.1	170.7
r_0 (fm)	1.12	1.15	1.16
a (fm)	0.78	0.739	0.752
W (MeV)	4.14	19.0	21.5
W_D (MeV)	5.08, 5.30, 5.53	0.0	0.0
r'_0 (fm)	1.32	1.515	1.498
a' (fm)	0.57, 0.58, 0.60	0.758	0.817
V_s (MeV)	6.2	0.0	0.0
r_s (fm)	0.98	0.0	0.0
a_s (fm)	0.75	0.0	0.0
r_c (fm)	1.20	1.4	1.25

[a] Reference 11.
[b] Reference 12.

TABLE III. Levels in ^{92}Mo observed with the ^{94}Mo(p,t) reaction. The enhancement values are based on a choice of D_0^2 as discussed in the text. The listed spin-parity assignments are based on the present work. Excitation energies are ±0.005 MeV.

Peak No	E^* (MeV)	J^π	L	Assumed transition	$B^2(j_1j_2J)$	$\mathcal{E}$
g.s.	0.000	0^+	0	a	1.0	1.5
1	1.505	2^+	2	a	1.0	0.3
2	2.275	(4^+)	(4)			
3	2.515	0^+	0	a, b	1.0, 1.0	0.07, 0.7
4	2.845	3^-	3	c	2.33	0.5
5	3.090					
6	3.535	2^+	2	d	1.67	0.09
7	3.835	0^+	0	b	1.0	3.5
8	3.915	2^+	2	d	1.67	0.14
9	4.140	4^+	4	d	3.0	0.6
10	4.300	2^+	2	d	1.67	0.40
11	4.485	2^+	2	d	1.67	0.14
12	5.150	0^+	0	b	1.0	0.25

[a] $[(^{92}\mathrm{Mo})_J(d_{5/2})^2_J]_0 \rightarrow (^{92}\mathrm{Mo})_J$.
[b] $(g_{9/2})^{10}_0 \rightarrow (g_{9/2})^8_0$.
[c] $[(f_{5/2})^6_0(d_{5/2})^2_0]_0 \rightarrow [(f_{5/2})^5_{5/2}(d_{5/2})]_J$.
[d] $[(g_{9/2})^{10}_0(d_{5/2})^2_0]_0 \rightarrow [(g_{9/2})^9_{9/2}(d_{5/2})]_J$.

TABLE IV. Levels in ^{94}Mo observed with the ^{96}Mo(p,t) reaction. The enhancement values are based on a choice of D_0^2 as discussed in the text. The listed spin-parity assignments are based on the present work. Excitation energies are ±0.005 MeV.

Peak No.	E^* (MeV)	J^π	L	Assumed transition	$B^2(j_1j_2J)$	$\mathcal{E}$
g.s.	0.000	0^+	0	a	1.33	1.8
1	0.870	2^+	2	a	1.67	0.18
2	1.575	4^+	4	a	3.00	0.6
3	1.865	(2^+)	(2)	a	1.67	0.06
4	2.070	2^+	2	a	1.67	0.5
5	2.300	$(4^+, 3^-)$	(4, 3)	a, b	3.0, 4.67	0.10, 0.15
6	2.395	2^+	2	a	1.67	0.035
7	2.425					
8	2.540	(5^-)	(5)	c	3.667	0.20
9	2.570	4^+	4	a	3.0	0.11
10	2.615					
11	2.775					
12	2.870					
13	3.320	0^+	0	d	1.0	0.75
14	3.375	(5^-)	(5)	a, c	3.0, 3.667	0.06, 0.04
15	3.405	2^+	2	d, e	5.0, 3.33	0.25, 0.07
16	3.455	(2^+)	(2)			
17	3.700	0^+	0	d	1.0	2.0
18	3.800	3^-	3	c	2.333	0.2
19	3.995	2^+	2	d	5.0	0.3
20	4.095	2^+	2	d	5.0	0.8
21	4.140	2^+	2	d	5.0	0.3

[a] $(d_{5/2})^4_0 \rightarrow (d_{5/2})^2_J$.
[b] $[(p_{3/2})^4_0(d_{5/2})^4_0]_0 \rightarrow [(p_{3/2})^3_{3/2}(d_{5/2})^3_{5/2}]_J$.
[c] $[(f_{5/2})^2_0(d_{5/2})^6_0]_0 \rightarrow [(f_{5/2})(d_{5/2})^5]_J$.
[d] $(g_{9/2})^{10}_0 \rightarrow (g_{9/2})^8_J$.
[e] $[(g_{9/2})^{10}_0(d_{5/2})_0]^4_0 \rightarrow [(g_{9/2})^9_{9/2}(d_{5/2})^3_{5/2}]_J$.

C. Levels in ^{94}Mo

The observed levels in ^{94}Mo are summarized in Table IV and compared with results from selected previous studies[17-20] in Fig. 6.

The level at 2.070 MeV shows no indication of an $L=0$ component. Instead, the angular distribution favors strongly a 2^+ assignment to this state. This is somewhat disappointing since the shell-model calculations discussed in the following section predict two excited 0^+ levels near 2 MeV of excitation in ^{94}Mo. These levels are predicted to be populated weakly by the ^{96}Mo(p, t) reaction and the possibility must be considered that an accidental degeneracy in energy of 0^+ and 2^+ levels obscures the weak 0^+. There seems to be little doubt that this reaction has missed the expected low-lying 0^+ excited states, although the limit of detection for $L=0$ transitions not obscured by other states was about 0.2% of the ground-state intensity in this region.

The assignment of 4^+ is favored for the level at 2.30 MeV on the basis of the positive parity determined by the (^{3}He, d) study.[20] The present work assigns 2^+ to the 2.39-MeV level which is within the limits determined by the decay scheme results.[17] The level at 2.54 MeV appears to be another candidate for an unresolved doublet. The inelastic proton data[19] clearly establish a collective 3^- level at this energy, but the (p, t) data favor a 5^- assignment. However, the low intensity seen for the collective 3^- in the Zr(p, t) studies[2] is not inconsistent with the $L=3$ being obscured in the present case.

The levels for which no assignment is given for the (p, t) work are all weakly excited and show rather featureless angular distributions consistent with $L \geq 5$.

The distribution of $L=2$ transfer strength among the 2^+ levels is quite interesting. Here, with four valence neutrons in the initial state, it should be relatively easy to populate the lowest 2^+ level. Nevertheless, the lowest 2^+ in ^{94}Mo is not populated appreciably stronger than the first 2^+ in ^{92}Mo. This is a striking change from the behavior observed for the analogous transitions in the zirconium isotopes where the lowest 2^+ in ^{92}Zr is populated almost an order of magnitude more strongly than the 2^+ in ^{90}Zr. In ^{92}Zr the first 2^+ is more than twice as intense as any other 2^+ level, while in ^{94}Mo the first 2^+ is less than half as strong as the 2^+ level at 2.07 MeV. It has been pointed out previously[20] that the population of these 2^+ levels

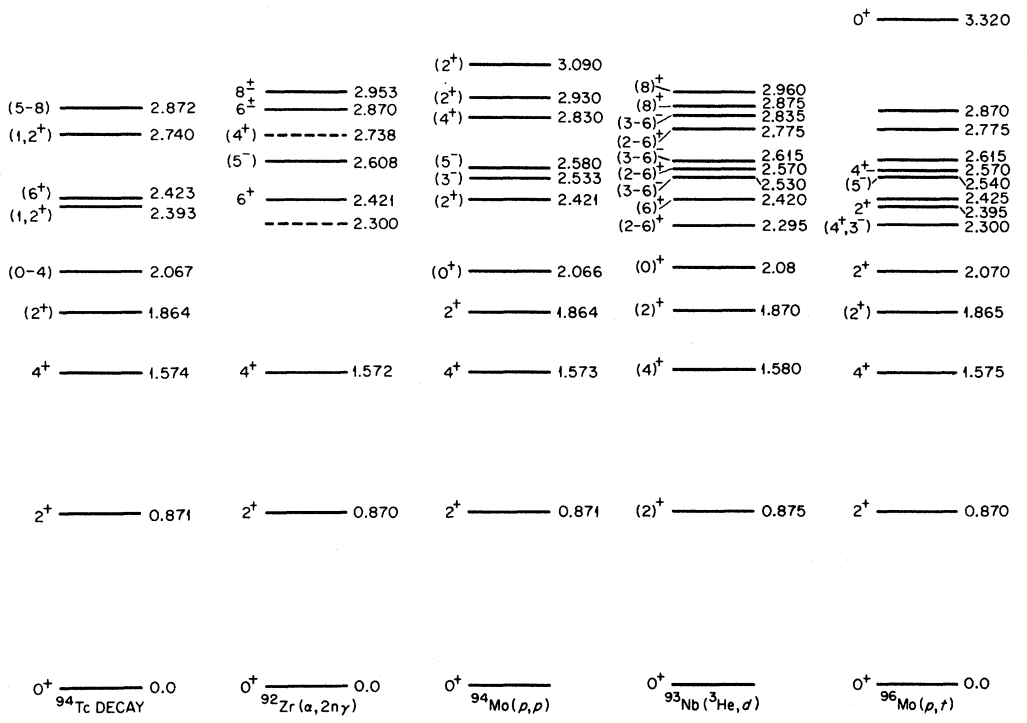

FIG. 6. Selected experimental data on the low-lying energy levels of ^{94}Mo. The decay data are taken from Ref. 17, the $(\alpha, 2n\gamma)$ data from Ref. 18, the (p, p') data from Ref. 19, the (^{3}He, d) data from Ref. 20, and the (p, t) data from the present study.

TABLE V. Comparison of (p, t) enhancement factors predicted by the extended shell-model calculations with those measured experimentally. Both enhancements are expressed as a ratio to the predicted strength for a pure $(d_{5/2})^n$ configuration.

Reaction	E^* (MeV)	J^π	$\mathcal{S}_{exp}$	$\mathcal{S}_{SM}$
^{94}Mo→ ^{92}Mo	0.00	0^+	1.5	1.5
		2^+	0.3	0.4
^{96}Mo→ ^{94}Mo	0.00	0^+	1.8	1.7
	0.87	2^+	0.18	0.2
	1.87	2^+	0.06	0.03
	2.07	2^+	0.5	0.9

in the ^{93}Nb(^{3}He, d) proton-transfer reaction does not agree with simple shell-model predictions. Again the presence of considerable configuration mixing in the wave functions seems apparent and points to the need for more complete calculations. An example of such a calculation is given in the following section.

D. Comparison with Shell-Model Calculations

The enhancement factors shown in Tables III and IV were obtained by assuming that a single configuration for the transferred neutron pair was responsible for the transition. This simplification was introduced to allow a more meaningful systematization of the data. The observed deviations of enhancement factors from unity indicate the inadequacy of the simple wave functions.

In a previous analysis[2] of the zirconium (p, t) reactions we included a comparison of intensities for a few low-lying states with predictions from an extended shell-model calculation. We have enlarged the scope of these calculations to include the molybdenum isotopes of interest in the present study. The model assumes an inert ^{88}Sr core with four protons distributed in the $1g_{9/2}$ and $2p_{1/2}$ orbitals and the appropriate number of neutrons distributed over the complete space of the $2d_{5/2}$, $2d_{3/2}$, and $3s_{1/2}$ orbitals. The wave functions and two-particle-transfer overlaps, $B(j_1 j_2 J)$, were calculated with the Oak Ridge–Rochester shell-model program[21] and the multiple-configuration DWBA calculation performed with the code JULIE. The enhancement factors obtained from these calculations are shown in Table V.

As in the zirconium case, the extended wave functions reproduce the ground-state $L = 0$ strengths very well. Thus, the ground state changes from isotope to isotope, as well as from zirconium to molybdenum, seem to be dominated by the selected model space. The interactions used in the calculations are apparently introducing somewhat too much $L = 2$ transition intensity into the low-lying levels, but the previously discussed behavior of the observed enhancements for the 2^+ levels in ^{94}Mo is predicted fairly well by the model wave functions. The over-all agreement between calculation and experiment seems quite encouraging.

Comparisons to higher L transfers have not been made because of the omission of the $1g_{7/2}$ neutron orbital from the calculations. With the inclusion of this orbital, calculations using this shell-model basis space seem quite capable of producing a good description of the low-lying level structure and the one- and two-neutron-transfer strengths for nuclei in this mass region.

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Investigation of the Nonunique First-Forbidden β Decay. I. Analysis of the $2^-(0.962\ \text{MeV})2^+$ β Transition in ^{198}Au

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A detailed study of the 0.962-MeV β transition from the decay of ^{198}Au is performed. A complete description of the theoretical formalism employed is given. Two sets of nuclear matrix elements have been extracted from the experimental data. In one of them the β moment of multipolarity $\lambda=2$ is of the same order of magnitude as those of multipolarities $\lambda=0$ and $\lambda=1$ and the ratio $\Lambda(=\langle\vec{\alpha}\rangle/\xi\langle i\vec{r}\rangle)$ is consistent with the Fujita-Eichler estimate [Λ(FE) $=2.4$]. In the second case the β moment of $\lambda=2$ is negligible and the ratio Λ is strongly reduced with respect to Λ(FE). A possible mechanism for the reduction of the β moments from their single-particle values is discussed on the basis of a particle-plus-phonon coupling model. It is concluded that the state $2f_{5/2}$ is the dominant neutron single-particle configuration in the ground state of ^{198}Au.

I. INTRODUCTION

Once the $V-A$ structure for the weak Hamiltonian had been well established, further progress was made to relate the β decay with other properties of the nucleus.[1-12] The weak Hamiltonian is expressed as

$$H_{\text{int}}=g_\beta[g_A(\vec{\sigma}\cdot\vec{\mathbf{L}}_4-\gamma_5 L_4)+g_V(\vec{\alpha}\cdot\vec{\mathbf{L}}_2-L_2)], \quad \text{(I.1)}$$

where $\vec{\mathbf{L}}_i$ and L_i are the appropriate combinations of the lepton wave functions defined by Alaga[13]; g_β is the semileptonic weak-coupling constant; g_A and g_V are the effective axial-vector and vector coupling constants, respectively ($g_A=-1.19$ and $g_V=1.0$).

In this Hamiltonian, the effects induced by the strong interactions (pseudoscalar and pseudotensor) are not taken into account; in addition, the higher-order terms (third forbidden) in the multipole expansion are neglected. Although these effects are relevant in $0^-\to 0^+$ and unique first-forbidden β transitions,[14,15] they are generally not important in nonunique β transitions. They may only be significant when the ξ approximation is not valid (see below) and/or when the leading β moments are strongly reduced by some selection-rule effect (for example l forbiddenness).

On performing the multipole expansion of the Hamiltonian (I.1) for the case of first-forbidden transitions, there remain six lowest-order β moments. They are listed in Table I.

The relativistic β moments are usually related to the corresponding nonrelativistic ones by defining the ratios

$$\Lambda=\langle\vec{\alpha}\rangle/\xi\langle i\vec{\mathbf{r}}\rangle$$

and

$$\Lambda_0=\langle\gamma_5\rangle/\xi\langle i\vec{\sigma}\cdot\vec{\mathbf{r}}\rangle \quad \text{(I.2)}$$

with $\xi=\alpha Z/2r_0$, where α is the fine-structure con-