Study of the $^{39}K(d, t)^{38}K$ Reaction at $E_d=23$ MeV*

H. T. FORTUNE, N. G. PUTTASWAMY,† AND J. L. YNTEMA
Argonne National Laboratory, Argonne, Illinois 60439

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The $^{39}K(d, t)^{38}K$ reaction has been utilized to study states in ^{38}K below an excitation energy of 5 MeV. Spectroscopic factors have been extracted by comparing the data with distorted-wave calculations. For states for which both $l=0$ and $l=2$ transitions are allowed, attempts have been made to extract relative admixtures. Two positive-parity states, not previously reported in neutron-pickup experiments, have been observed at $E_x=3.44$ and 3.99 MeV. Two weak negative-parity states have been observed at $E_x=2.64$ ($l=1$) and 4.66 MeV ($l=3$), indicating the admixture of core-excited configurations in the ground-state wave function of ^{39}K.

I. INTRODUCTION

NUCLEI in the $2s$-$1d$ shell have received considerable attention in recent years. Glaudemans *et al.*[1] have performed a shell-model calculation assuming that ^{28}Si forms an inert core filling the $d_{5/2}$ shell. Lawson[2] has done a calculation permitting excitations from the $d_{5/2}$ shell. More recently, attempts have been made[3] to include many more nucleon configurations within the $d_{5/2}$-$s_{1/2}$-$d_{3/2}$ shells. Such calculations predict the level energies and spectroscopic factors for single-nucleon–transfer reactions. For comparison with these theoretical calculations, one would like to study pickup and stripping reactions experimentally. Neutron pickup, for example, can be studied via the (p, d), (d, t), and $(^3He, \alpha)$ reactions. It is known that these reactions are sensitive to certain l values for neutron pickup.

In particular, a study of the $^{39}K(^3He, \alpha)^{38}K$ reaction[4] has not yielded any significant $l=0$ strength. The present experiment was undertaken to find the expected $l=0$ strength and also to look for any pickup involving odd values of l. Meanwhile, results from the (p, d) reaction[5] have become available, and one is now in a position to make a detailed comparison with the theoretical predictions.

II. EXPERIMENTAL PROCEDURE

The experiment was performed at the Argonne cyclotron with a deuteron beam of energy 22.80 ± 0.05 MeV. The 60-in. scattering chamber[6] was used along with the standard (dE/dx)-E counter arrangement for identifying the tritons. Particles were selected by displaying the output of the pulse-multiplier circuit and the $(E+\Delta E)$ pulses on a two-dimensional analyzer. The pulse-multiplier output and the gate set on the tritons were continuously monitored on a 400-channel analyzer. Targets were prepared by evaporating natural potassum iodide (^{39}K abundance=93%) on thin carbon backings. The target thickness was determined by taking spectra of deuterons elastically scattered by the target at angles from 30° to 60°. The peak value of the elastic scattering cross section was then compared with the prediction from the deuteron optical-model parameters (to be described next) used in the distorted-wave calculation.

It was assumed that the elastic scattering cross sections from ^{39}K and ^{41}K were equal, so 7% of the total deuteron yield was subtracted to obtain the ^{39}K contribution. This method yielded a target thickness of 150 $\mu g/cm^2$. In cases in which the optical-model potential is known to fit the elastic scattering data, this technique has proved to have an uncertainty less than 10%. However, when the optical-model potential is taken from other analyses (as is the case here), the expected uncertainty in the target thickness obtained is perhaps as large as 20%.

Triton spectra were taken at laboratory angles between 12° and 30°, in 3° steps. A typical spectrum at 18° is shown in Fig. 1. A consistent energy calibration was achieved by using triton spectra from the $^{41}K(d, t)$ and $^{48}Ti(d, t)$ reactions. The peaks in Fig. 1 are labeled by the excitation energies in ^{38}K. Angular distributions (for all the states except the 0.13-MeV state) were obtained by adding the counts under each peak and subtracting a reasonable background. Since the experimental resolution was not sufficient to resolve the first excited state at 0.13 MeV from the ground state, a peak-fitting procedure was used wherein two peaks, of the same shape and 0.13 MeV apart, were fitted to the experimental counts around the region of the two states. In estimating the error in the cross section, the contributions due to statistics and uncertainties in background subtraction were calculated, and, in the case of the 0.13-MeV state, the error estimated by the peak-shape-fitting procedure was also included.

III. ANALYSIS

The experimental angular distributions were compared with distorted-wave Born-approximation (DWBA) cal-

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† Present address: Department of Physics, Central College, Bangalore University, Bangalore, Mysore State, India.

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[2] R. D. Lawson (private communication).

[3] B. H. Wildenthal, J. B. McGrory, E. C. Halbert, and P. W. M. Glaudemans, Phys. Letters **26B**, 692 (1968).

[4] L. M. Blau, W. Parker Alford, D. Cline, and H. E. Gove, Nucl. Phys. **76**, 45 (1966).

[5] A. Anderson and P. Bevington (to be published); A. Anderson (private communication).

[6] J. L. Yntema and W. Ostrander, Nucl. Instr. Methods **16**, 69 (1962).

culations from the code JULIE[7] by use of the relation

$$\sigma_{\text{expt}}(\theta) = NC^2 \sum_{l,j} S_{lj}\sigma_{lj}(\theta). \quad (1)$$

For a (d, t) reaction, according to Bassel[8] the normalization factor has the value $N = 3.33$ with a possible uncertainty of 10%. The quantity C is an isospin Clebsch-Gordan coefficient, $C = (T_0, t, T_{0z}, t_z \mid TT_z)$, where T = initial isospin (target), t = isospin of transferred particle, and T_0 = final isospin (residual nucleus). For the ^{39}K(d, t)^{38}K reaction, the two possibilities are $C^2 = 1$ for $T_0 = 0$ and $C^2 = \frac{1}{3}$ for $T_0 = 1$.

The optical-model parameters used in the DWBA calculations were taken from earlier work in this mass region.[9,10] The bound-state form factor for the neutron transferred to a state in ^{38}K was taken to be the wave function of a neutron in a Woods-Saxon well, with a binding energy equal to the sum of the separation energy of a neutron from ^{39}K and the excitation energy of the state in ^{38}K. The bound-state and optical-model parameters are listed in Table I.

The DWBA calculations—all local, zero range—were performed for lower cutoff radii $R_{co} = 0$ and 6 F as well as for several closely spaced values near the nuclear surface ($R \approx 3$ F). A plot of the spectroscopic factor as a function of the lower cutoff has a local maximum at 3.05 F. This may be seen from Fig. 2, in which σ_{max} from a DWBA calculation is plotted versus R_{co}. Preliminary calculations were performed to investigate the possibility of any forward-angle J dependence for $l = 2$. However, calculations for $\Delta J = \frac{3}{2}$ and $\Delta J = \frac{5}{2}$ were found to be virtually equivalent in shape, though different in magnitude. [For $Q = -10.27$ MeV, the JULIE code gives the ratio $\sigma(\frac{5}{2})/\sigma(\frac{3}{2}) = 1.45$.] Thus, most of the $l = 2$ calculations were performed for $\Delta J = \frac{3}{2}$ only.

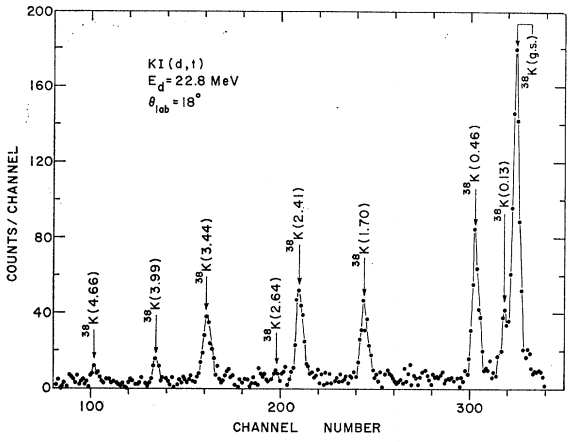

FIG. 1. Triton spectrum from deuteron bombardment of KI target (natural abundance). Only the strong states for which angular distributions were extracted are identified.

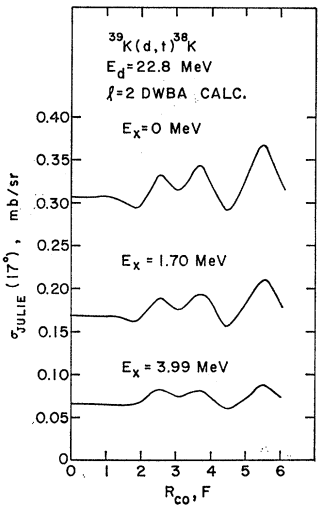

FIG. 2. Behavior of DWBA peak cross section as a function of the lower cutoff radius for $l = 2$, $J = \frac{3}{2}$. The curves were calculated with the parameters listed in Table I.

The calculations, however, did exhibit a pronounced effect on the Q value (as can be seen in Fig. 3). This dependence was as great for $R_{co} = 0$ as for $R_{co} > 0$. In most cases, spectroscopic factors were obtained for lower cutoff radii of 0, 3.05, and 6.0 F.

Most of the low-lying states in ^{38}K that are reached in the ^{39}K(d, t)^{38}K reaction are characterized by $l = 0$ or $l = 2$, or both. Where both l values are possible, the relative admixtures for the two possible l values were obtained by minimizing (with respect to A and B) the quantity

$$\chi^2 = N^{-1} \sum_{i=1}^{N} \frac{\{A[\sigma_0(\theta_i) + B\sigma_2(\theta_i)] - \sigma_{\text{expt}}(\theta_i)\}^2}{(\Delta\sigma_i)^2}, \quad (2)$$

where N is the number of data points in the angular distribution, σ_0 and σ_2 are the theoretical angular distributions for $l = 0$ and 2, respectively, σ_{expt} is the experimental cross section, and $\Delta\sigma$ is the error associated with this cross section.

It is well known that the results of such attempts to obtain admixtures can be extremely sensitive to the exact shapes assumed for the theoretical curves. And, in fact, the shape to be used for $l = 0$ is not at all unambiguous. It has frequently been observed that the angle at which the secondary maximum in an $l = 0$ angular distribution is predicted (by a DWBA calculation) often is somewhat greater than the angle at which this maximum is observed experimentally. For these reasons, the χ^2 minimization procedure was carried out for a variety of $l = 0$ and $l = 2$ shapes. In general, the fits obtained were better when DWBA calculations, rather than "empirical" shapes, were used for σ_0 and σ_2. This point will be further discussed below in connection with the 0.46-MeV state.

[7] R. H. Bassel, R. M. Drisko, and G. R. Satchler, Oak Ridge National Laboratory Report No. ORNL-3240, 1962 (unpublished).
[8] R. H. Bassel, Phys. Rev. **149**, 791 (1966).
[9] J. L. Yntema and G. R. Satchler, Phys. Rev. **134**, B976 (1964).
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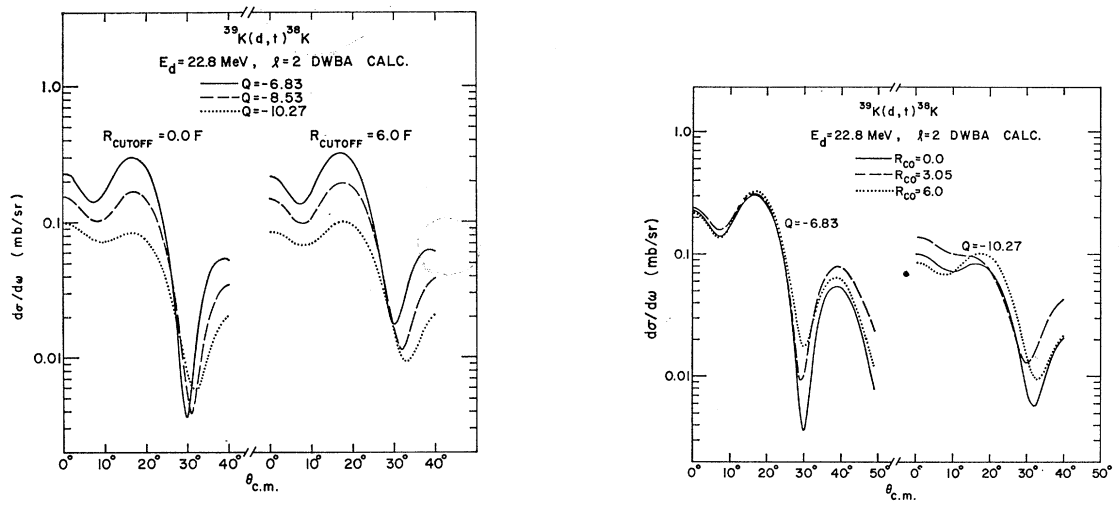

FIG. 3. Dependence of the DWBA angular distributions on the lower cutoff radius and on the Q value. (a) Calculations at $R_{co}=0$ and 6.0 F for different Q values. (b) Calculations for $Q=-6.83$ and -10.27 MeV for different lower cutoff radii.

These admixture calculations suffer from another ambiguity. The DWBA calculations for $l=0$ invariably have deeper minima than the data for pure $l=0$ transitions. The admixture calculations tend to fill in these minima by overestimating the magnitude of the $l\neq 0$ component, and their results may indicate $l\neq 0$ admixtures even for known pure $l=0$ transitions. Thus for states with large $l=0$ strength in the present case, care must be exercised in order not to overestimate the $l=2$ strength.

IV. DISCUSSION

A. Ground State

The ground state of ^{38}K is known[11] to have $J^\pi=3^+$. Therefore, except for the (unlikely) possibility of some g-wave admixture in the ground state of ^{39}K, the angular distribution to this state must be pure $l=2$. The spectroscopic factor for this state is predicted by Glaudemans *et al.*[1] to be 1.75 and by Lawson[2] to be 1.70. The value obtained from the present experiment is 1.71–1.83, depending on the value of the lower cutoff used. The resulting fit is shown in Fig. 4.

This good agreement between the experimental and theoretical spectroscopic factors is probably fortuitous. The method used to obtain the target thickness is expected to have an uncertainty as large as 20%. In addition, reasonable changes in the parameters of the bound-state potential well can change the value of the extracted spectroscopic factor by 20% or more. [However, none of these parameters were varied to obtain this agreement with theory; rather, they were taken (unchanged) from an analysis of other data[9,10] in this

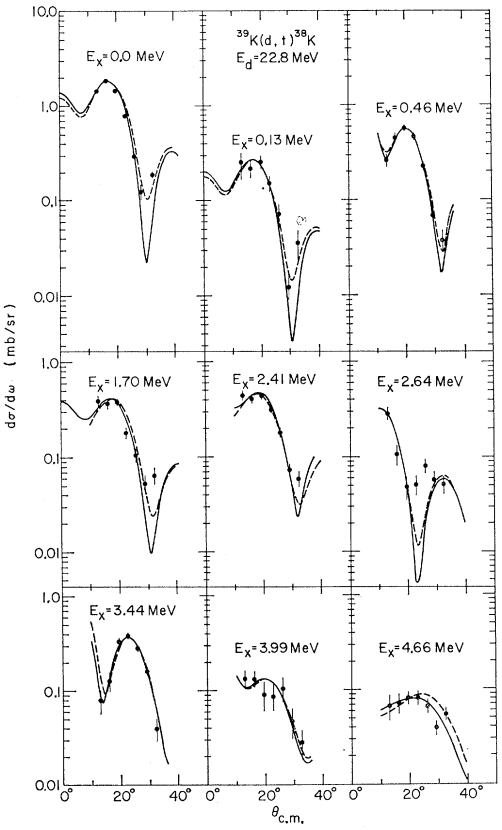

FIG. 4. Angular distributions of states strongly populated in the ^{39}K$(d, t)^{38}$K reaction. The curves were calculated by use of the parameters listed in Table I and for lower cutoff radii $R_{co}=0$ (solid curve) and $R_{co}=6.0$ F (dashed curve). For cases in which both $l=0$ and $l=2$ are possible, the curves shown are linear combinations of the two cross sections as explained in the text. The points represent the experimental values.

[11] P. M. Endt and C. Van der Leun, Nucl. Phys. **A105**, 1 (1967), and references therein.

TABLE I. Optical-model parameters used in the analysis of the ^{39}K(d, t)^{38}K reaction.

	V (MeV)	W (MeV)	W_D (MeV)	V_{so} (MeV)	r_0 (F)	a (F)	r_0' (F)	a' (F)	r_{0c} (F)
d+^{39}K [a]	105	0	20.0	6.0	1.020	0.8600	1.420	0.650	1.30
t+^{38}K [b]	177	14.7	0	8.0	1.138	0.7236	1.602	0.769	1.40
n+^{38}K	adjusted	...	...	λ=25	1.20	0.65	...	...	...

[a] Reference 9. [b] Reference 10.

mass region.] Thus, the absolute value of the ground-state spectroscopic factor is assigned an uncertainty of ±30%. Of course, the spectroscopic factors for the excited states (*relative to the ground-state value*) are not subject to either of the uncertainties mentioned above. For this reason, these *relative* spectroscopic factors are expected to have uncertainties of only a few percent. One of the major sources of uncertainty in the relative spectroscopic factors for the excited states is the energy dependence of the exit channel (triton) optical-model parameters. For all the results quoted here, the same value of W (imaginary well depth) was used for all the excited states. If, however, W is changed according to the formula

$$W(E_x) = W_{(g.s.)} - 0.5E_x,$$

then the value of the spectroscopic factors for both l=0 and l=2 are reduced for higher excited states, the reduction being about 2.5% per MeV of excitation.

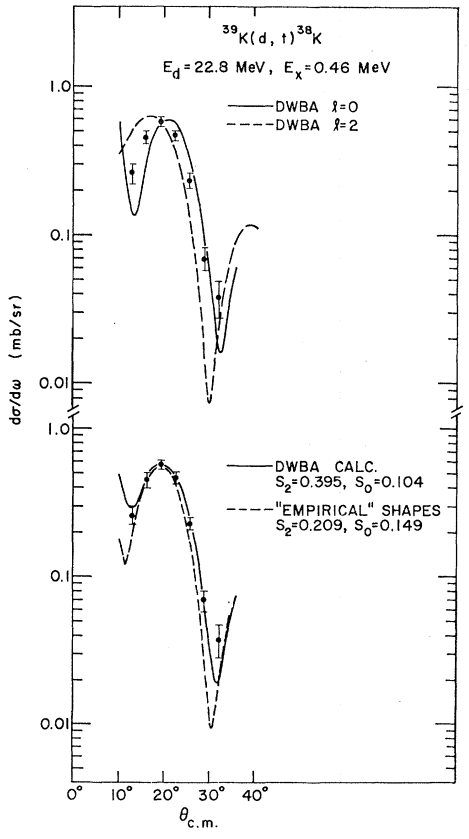

FIG. 5. Measured angular distributions (points) and DWBA calculations (curves) for the state at E_x=0.46 MeV. The top half of the figure shows calculations for pure l=0 (solid) and pure l=2 (dashed). The bottom half shows results of attempts to extract relative admixtures by use of empirical shapes (dashed) and shapes from DWBA calculations (solid).

B. 0.13-MeV State

The angular distribution of the reaction to the state at 0.13 MeV has large uncertainties because this peak in the spectrum (Fig. 1) is not completely resolved from the much larger ground-state peak. The errors shown in Fig. 4 for this state are a combination of statistical errors and estimated errors in the peak-fitting procedure.

This state is known[11] to have J^π=0$^+$, T=1, and is expected to have a pure l=2 angular distribution. The fit to the data is shown in Fig. 4. The predicted values[1] C^2S=0.23 and[2] 0.24 are in good agreement with the extracted values 0.250–0.264.

C. 0.45-MeV State

Both Glaudemans *et al.*[1] and Lawson[2] predict a J^π=1$^+$, T=0 state in this energy region, its predominant components being $(d_{3/2})^{-2}$ and $(d_{3/2})^{-1}(s_{1/2})^{-1}$. Glaudemans *et al.* predict 64% of the $(s_{1/2})^{-1}(d_{3/2})^{-1}$ configuration and 35% of the $(d_{3/2})^{-2}$ configuration for this state so that S_2=0.27, S_0=0.24; Lawson predicts 28 and 60% so that S_2=0.46, S_0=0.10. Two previous

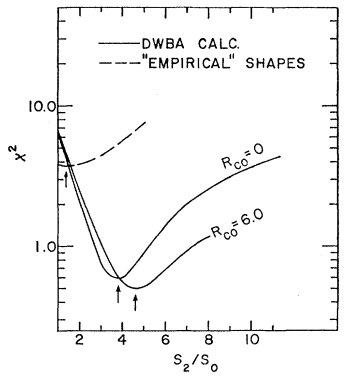

FIG. 6. Values of χ^2 as a function of the admixture S_2/S_0 for the 0.46-MeV state. The dashed curves were obtained with empirical shapes, the solid ones with shapes obtained from DWBA calculations. The χ^2 minima are much sharper for shapes obtained from DWBA calculations.

TABLE II. Results of various admixture calculations for the 0.46-MeV state.

Procedure[a]	Cutoff radius (F)	S_2	S_0	χ^2
1. σ_0 and σ_2 from DWBA	0.0	0.395	0.104	0.56
	6.0	0.387	0.084	0.50
2. σ_0 from DWBA, "empirical" σ_2	0.0	0.344	0.118	0.48
3. "empirical" σ_0 and σ_2	···	0.181	0.155	3.10
4. σ_2 from DWBA, "empirical" σ_0	0.0	0.209	0.149	3.80
	6.0	0.270	0.112	3.60

[a] See text for explanation.

neutron-pickup reactions to the 0.46-MeV state give conflicting results. Blau *et al.*,[4] from a study of the ^{39}K(^{3}He, α) reaction, assign $l=2$, $S_2=0.32$ to this state, while Anderson and Bevington[5] assign $l=0$, $S_0=0.11$ in the ^{39}K(p, d) reaction.

In the present experiment, the angular distribution (Fig. 5) for this state seems to show an admixture of $l=0$ and $l=2$. In attempts to obtain the relative admixtures, a number of different assumptions were made concerning the theoretical angular distributions for $l=0$ and $l=2$. First of all, it was assumed that σ_0 and σ_2 were as given by DWBA calculations with the optical-model parameters listed in Table I. The χ^2 fitting procedure was then carried out for lower cutoff radii of 0, 3.05, and 6.0 F. The curve of χ^2 versus S_2/S_0 is shown in Fig. 6. The angular distributions resulting from this procedure are shown in Fig. 4 and in the lower half of Fig. 5. The resulting spectroscopic factors are $S_2=0.387$–0.395, $S_0=0.084$–0.104, in reasonable agreement with the predictions of Lawson but not with those of Glaudemans *et al.*[1]

In a second attempt at fitting, the DWBA prediction for σ_0 was used, but the $l=2$ shape was an empirical one given by the experimental ground-state angular distribution. The resulting fit was changed but little from the result of procedure 1. This was, of course, to be expected since the DWBA prediction reproduces the ground-state angular distribution rather well.

In a third procedure, "empirical" shapes were assumed for both $l=0$ and $l=2$. The $l=2$ shape was again taken to be that of the ^{39}K(d, t)^{38}K(g.s.) angular distribution, while the $l=0$ shape was taken from pure $l=0$ experimental angular distributions in neighboring nuclei. The resulting χ^2 calculation (Fig. 6) had a very shallow minimum corresponding to the values (Tables II) $S_2=0.21$–0.27, $S_0=0.11$–0.15, which differ significantly from the results of procedure 1.

However, the value of χ^2 obtained in procedure 3 changes by only 30% when procedure 3 is forced to give the results of procedure 1. Because of the much shallower χ^2 minimum and correspondingly poorer fit, it appears that it is better to use the results of DWBA calculations rather than empirical shapes from neighboring nuclei when extracting relative admixtures of mixed l values. In fact, relative results of procedure 3 were even worse for the states at 1.70 and 2.41 MeV. Thus, it is believed that the spectroscopic factors obtained from the first procedure are the more reliable. These are the values listed in Table III. These spectroscopic factors, of course, should be viewed with a bit of caution, since any attempt to extract relative admixtures contains a rather large uncertainty, and

TABLE III. Excitation energies and spectroscopic factors for levels observed in the ^{39}K(d, t)^{38}K reaction.

E_x (MeV)	J^π, T	l	Value of C^2S $R_{co}=0.0$ F	3.05 F	6.0 F
0	3^+, 0	2	1.826 (1.0)[a]	1.75	1.712
0.128±0.020	0^+, 1	2	0.264 (0.14)	0.26	0.250
0.456±0.010	$(1)^+$, 0	2	0.395[b] (0.22)	0.37	0.387
		0	0.104[b] (0.057)	0.10	0.084
1.704±0.010	$(1)^+$, 0	2	0.75[c] (0.41)	0.66	0.63
		0	0.0(0.0)	0.0	0.0
2.405±0.010	$(2)^+$, 1	2	1.02 (0.56)	0.91	0.92
		0	0.054 (0.030)	0.051	0.009
2.639±0.015	$(0, 1, 2, 3)^-$	1	0.090 (0.049)		0.087
3.441±0.015	$(2)^+$, 0	2	0.268[d] (0.15)	0.22	0.243
		0	0.335[d] (0.18)	0.22	0.346
3.989±0.015	$(2)^+$, 1	2	0.504 (0.28)	0.37	0.446
		0	0.063 (0.034)	0.051	0.064
4.66±0.02	$(2, 3, 4, 5)^-$	3	0.51 (0.28)		0.48
			$\Sigma C^2S(l=2)=5.03$	4.54	4.59
			$\Sigma C^2S(l=0)=0.56$	0.42	0.50

[a] The numbers in parentheses are the spectroscopic factors relative to the ground state.

[b] Assuming a pure $l=0$ transition yields $C^2S_0=0.18$.

[c] Assuming $\Delta J=\frac{5}{2}$ (rather than $\frac{3}{2}$) yields $C^2S_2=0.52$.

[d] Assuming a pure $l=0$ transition yields $C^2S_0=0.38$.

the $l=2$ component of the states at 0.46 and 3.44 MeV may be overestimated.

D. 1.70-MeV State

Both Glaudemans *et al.*[1] and Lawson[2] predict a second $J^\pi=1^+$, $T=0$ state 1–2 MeV above the first. Both calculations predict a mixture of $l=0$ and $l=2$ for neutron pickup to this state; Glaudemans *et al.* predict $S_2=0.48$, $S_0=0.13$, whereas Lawson predicts $S_2=0.18$, $S_0=0.11$. Glaudemans *et al.*, who included only $d_{3/2}$ and $s_{1/2}$ in their set of basic states, predict this state to be a mixture of 35% $(d_{3/2})^{-1}(s_{1/2})^{-1}$ and 65% $(d_{3/2})^{-2}$. Lawson, on the other hand, includes $d_{5/2}$ as well. In fact, most of his $l=2$ strength for this state is from the configuration $(d_{5/2})^{-1}(d_{3/2})^{-1}$. [Lawson predicts 44% $(d_{5/2})^{-1}(d_{3/2})^{-1}$, 30% $(s_{1/2})^{-1}(d_{3/2})^{-1}$, and only 1% $(d_{3/2})^{-2}$.] This predicted state has been identified with the state observed experimentally at 1.70 MeV.

However, in both the (^{3}He, α) and the (p, d) work, this state exhibits a pure $l=2$ angular distribution. In the present work, all the different procedures of extracting relative admixtures give a minimum χ^2 for $S_0/S_2=0$. [In all the fitting, B in Eq. (2) was required to be positive.] Certainly we have $S_0/S_2<0.01$, from the present data. The fact that this state is seen reasonably strongly in the ^{40}Ca(d, α)^{38}K reaction would indicate that it indeed has $T=0$ and is not the second predicted $T=1$ state (which is expected to be higher). This state at 1.70 MeV, however, is more weakly excited in the (d, α) reaction than is the state at 0.46 MeV. This could perhaps indicate that the 1.70-MeV state is predominantly $(d_{5/2})^{-1}(d_{3/2})^{-1}$ rather than $(d_{3/2})^{-2}$ and $(s_{1/2})^{-2}$, which are the dominant configurations of the 0.46-MeV state.

Assuming $\Delta J=\frac{3}{2}$ for this state yields $C^2S_{3/2}=0.63$–0.75, whereas we have $C^2S_{5/2}=0.43$–0.52 if the transition is characterized by $\Delta J=\frac{5}{2}$. If this state really has $J^\pi=1^+$, however, it is rather surprising that the mixing with the 0.46-MeV state is so weak that the 1.70-MeV state has no $l=0$ strength. (One would have thought that the absence of $l=0$ strength would have indicated $J\neq1$, 2.) In the absence of any better evidence, however, we accept the tentative assignment $J^\pi=1^+$, $T=0$.

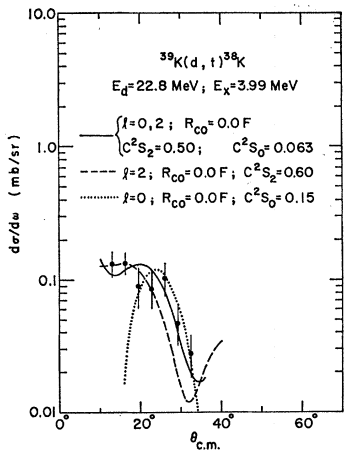

FIG. 7. Results of DWBA calculations for the state at 3.99 MeV for pure $l=0$ (dotted), pure $l=2$ (dashed), and admixed $l=0$ and $l=2$ (solid). Because of the large errors in $d\sigma/d\omega$, the spectroscopic factors for this state have large uncertainties.

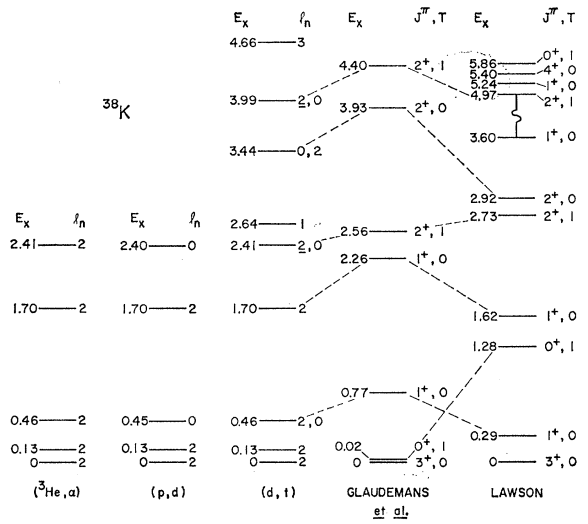

FIG. 8. Summary of existing data and calculations for neutron pickup from ^{39}K. The data for (^{3}He, α) are from Ref. 4, (p, d) from Ref. 5, and (d, t) from the present work. The calculations are those of Refs. 1 and 2. For further explanation, see the text and Table IV.

E. 2.41-MeV State

Both Glaudemans *et al.* and Lawson predict the fourth excited state of ^{38}K to have $J^\pi=2^+$, $T=1$, with only a small amount of s-wave admixture. Glaudemans *et al.* predict more s-wave strength ($C^2S_2=1.08$, $C^2S_0=0.08$) than does Lawson ($C^2S_2=1.17$, $C^2S_0=0.02$). This state is supposedly the state observed experimentally at 2.41 MeV. This identification is supported strongly by the fact that the 2.41-MeV state is observed only very weakly in the ^{40}Ca(d, α)^{38}K reaction.[11] From the present experiment, the admixture calculations give a best fit for the spectroscopic factors $C^2S_2=0.92$–1.02, $C^2S_0=0.01$–0.05, in reasonable agreement with both predictions.

F. Higher Excited States

Only two other positive-parity higher excited states are observed in the present experiment—at energies of 3.44 and 3.99 MeV. The admixture calculations give $C^2S_2=0.24$–0.27, $C^2S_0=0.34$–0.35 for the 3.44-MeV state and $C^2S_2=0.45$–0.50, $C^2S_0=0.063$–0.064 for the state at 3.99 MeV. Both Glaudemans *et al.* and Lawson predict two states ($J^\pi=2^+$, $T=0$ and $J^\pi=2^+$, $T=1$) near $E_x=4.0$ MeV. Supposedly, these are the two states observed at 3.44 and 3.99 MeV.

If the state at 3.44 MeV is assumed to be pure

TABLE IV. Experimental and theoretical spectroscopic factors for neutron pickup to low-lying states in ^{38}K.

			Relative spectroscopic factors $C^2S/(C^2S)_{g.s.}$ [a]						
			Values from neutron pickup reactions			Theoretical predictions: Glaudemans[e]		Lawson[f]	
E_x (MeV)	J^π, T	l	(p, d) [b]	$(^3\mathrm{He}, \alpha)$ [c]	(d, t) [d]	E_x (MeV)	$C^2S/(C^2S)_{g.s.}$	E_x (MeV)	$C^2S/(C^2S)_{g.s.}$
0.0	$3^+, 0$	2	0.90[a]	1.24[a]	1.83[a]	0.00	1.75[a]	0.00	1.70[a]
0.13	$0^+, 1$	2	0.29	0.25	0.14	0.02	0.14	1.28	0.14
0.46	$(1)^+, 0$	2	0.0	0.26	0.22	0.77	0.15	0.29	0.27
		0	0.11	0.01(±0.05)	0.06		0.14		0.06
1.70	$(1)^+, 0$	2	0.21	0.41	0.41	2.26	0.27	1.62	0.11
		0	0.00	0.02(±0.06)	0.00		0.074		0.065
2.41	$(2)^+, 1$	2	0.00	0.87	0.56	2.56	0.62	2.73	0.69
		0	0.25	0.01(±0.09)	0.03		0.046		0.01
	$\Sigma C^2S(l=2)=1.35$			3.46	4.26		3.82		3.76
	$\Sigma C^2S(l=0)=0.32$			~0	0.16		0.46		0.22

[a] The *absolute* spectroscopic factors are listed for the ground state only.
[b] Reference 5.
[c] Reference 4.
[d] Present work; the values listed are for $R_{co}=0$.
[e] Reference 1.
[f] Reference 2.

$l=0$, the value $C^2S_0=0.44$ is obtained. The state at 3.99 is relatively weak and the data (Fig. 7) have large errors. Assuming pure $l=0$ for this state yields $C^2S_0=0.15$, while a pure $l=2$ transition gives (for $d_{3/2}$) $C^2S_2=0.60$. Thus, the relative spectroscopic factors quoted in Table II for this state may be uncertain by as much as 50%.

Two negative-parity states are observed at energies of 2.64 and 4.66 MeV. The 2.64-MeV state has a characteristic $l=1$ angular distribution with a spectroscopic factor of 0.09. This is consistent with the small p-wave admixture of neutrons in ^{40}Ca.[11] The state at 4.66 MeV has an $l=3$ angular distribution, with a spectroscopic factor of 0.48–0.51. Neutron-pickup experiments[11] from ^{40}Ca have previously predicted $S=0.5$–1.0 for the $f_{7/2}$ admixture in the ground state of ^{40}Ca. The present result is consistent with those earlier measurements.

V. CONCLUSIONS

The results of the three neutron-pickup experiments to ^{38}K as well as the theoretical calculations of Glaudemans *et al.* and Lawson are summarized in Fig. 8 and in Table IV.

The angular distributions of $l=0$ and $l=2$ transfers in the (d, t) reaction at 23-MeV incident deuteron energy are quite different, and therefore the study of this reaction is very useful in those cases in which $l=0$ and $l=2$ transfers to the same level are permitted. From Table IV it is clear that the (p, d) reaction at 18 MeV on ^{39}K does not allow the extraction of an $l=2$ transition strength in the presence of an $l=0$ component even if the value of C^2S for this $l=0$ component is less than 10% of the one for the $l=2$ component. A similar insensitivity has been observed in the ^{48}Ca$(p, d)^{47}$Ca reaction[12] to the 2.60-MeV doublet.

[12] R. J. Peterson, Phys. Rev. **170**, 1003 (1968).

In the $(^3\mathrm{He}, \alpha)$ reaction at low incident energies, the $l=2$ transition is dominant and $l=0$ admixtures are difficult to extract.

The presence of core-excited configurations in the ground-state wave function of ^{39}K is not surprising. Such admixtures have been found in other nuclei in the *sd* shell.

The rather poor distorted-wave fit to the $l=1$ angular distribution has been observed for several known $l=1$ transitions in this region of the Periodic Table. In the study of the (d, t) reaction on the Ca isotopes, it was found that the techniques and parameters used in the present work gave $l=3$ strengths which were consistent with the sum-rule expectation, while for the $l=2$ and $l=0$ transitions these procedures yielded about 80% of the expected sum-rule strength.

In the present work, the summed $l=2$ strengths would indicate that at least some of the $l=2$ transitions involve $\Delta J=\frac{5}{2}$. Logical candidates for predominantly $d_{5/2}$ transfer (from the calculations of Lawson) would appear to be the states at 1.70 and 3.44 MeV. Assigning these transitions to be $\Delta J=\frac{5}{2}$ leaves a summed $d_{3/2}$ strength of 4.01, in reasonable agreement with the limit of 4.

The low value of the summed $l=0$ strength would appear to be significant. Even if the states at 0.46, 3.44, and 3.99 MeV were assigned pure $l=0$ transitions, the summed $l=0$ strengths would still be only 0.77, which is considerably short of the limit of 2.

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