

Excitation of  $6^-$  and  $7^+$  stretched states in the  $^{38}\text{Ar}(p,n)^{38}\text{K}$  reaction at 135 MeV

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High-spin, stretched-state excitations were studied in the  $^{38}\text{Ar}(p,n)^{38}\text{K}$  reaction at 135 MeV with the beam-swinger system at the Indiana University Cyclotron Facility. Neutron kinetic energies were measured by the time-of-flight technique with large-volume plastic-scintillator neutron detectors at flight paths ranging from 81 to 131 m. Overall time resolutions of about 825 ps provided energy resolutions from 320 to 450 keV. The target was a 4-cm-long gas cell filled to  $\sim 3$  atm absolute. Angular distributions were extracted for the low-lying excitations observed at wide angles. A known  $7^+$  state at  $E_x = 3.5$  MeV was observed, plus two states at 5.3 and 5.9 MeV, which are tentatively identified as  $6^-$  excitations, based on comparisons with distorted wave Born approximation and *sdpf* shell-model calculations. The  $^{38}\text{K}$  spectrum is in reasonable agreement with the shell-model calculations. In contrast to the analysis of 80 MeV  $^{40}\text{Ca}(d,\alpha)^{38}\text{Ar}$  measurements, these results do not indicate a significant problem for the nuclear shell model near  $A = 40$ .

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## I. INTRODUCTION

Although the nuclear shell model is over forty years old, there remain certain persistent difficulties. Among these difficulties is the structure of the doubly magic nucleus  $^{40}\text{Ca}$ . Exemplifying this problem is the paper of Zamick on the theory of core excitation of the Ca isotopes [1]. The structure for the ground state of  $^{40}\text{Ca}$  can be written as

$$\alpha(0p-0h) + \beta(2p-2h) + \gamma(4p-4h) + \dots, \quad (1)$$

where

$$\alpha^2 + \beta^2 + \gamma^2 + \dots = 1. \quad (2)$$

The number of neutron (or proton) holes is given by

$$G = \beta^2 + 2\gamma^2 + \dots. \quad (3)$$

Zamick, ignoring  $\gamma^2$  (which Gerace and Green [2] compute to be about 1%) finds  $G = 0.22$ ; however, an analysis [3] of a  $^{40}\text{Ca}(d,p)^{41}\text{Ca}(J^\pi = \frac{3}{2}^+)$  experiment yielded a value of 0.78 for  $G$ . Noting that in his model  $G = 1.0$  implies that the  $^{40}\text{Ca}$  ground state is entirely core excited, Zamick states that  $G = 0.78$  would require the unperturbed energy of the two-particle-two-hole (2p-2h) state to be lower than the simple shell-model state, which "would be a major catastrophe for the shell model."

One must suspect that the extraction of  $G$  from strip-

ping experiments may be rather uncertain. The results of other stripping and pickup experiments and of electron scattering on  $^{40}\text{Ca}$  emphasize this difficulty, as seen in Table I (from Table 2 of Brown, Masson, and Hodgson [4]), the extracted number of proton holes in  $^{40}\text{Ca}$  varies from 0.27 to 0.73, depending on experiment. More recently, Kramer *et al.* [5] find even larger values for the number of proton holes in  $^{40}\text{Ca}$  from  $^{40}\text{Ca}(e,e'p)$  proton knockout studies. Similarly, the  $^{40}\text{Ca}(d,p)$  work of Eckle *et al.* [6] finds there to be 1.04 neutron holes in the *s-d* shell orbitals in  $^{40}\text{Ca}$ . Theoretical calculations show similar variations, as shown in Table II. Additionally, theoretical estimates by Johnson and Mahaux [10] and by Tornow *et al.* [11,12] indicate relatively large proton occupancies for the  $f_{7/2}$  level in  $^{40}\text{Ca}$  ( $\sim 1.0$  proton). (These calculations are not presented in a form which allows one to extract values for  $\alpha^2$  or  $\beta^2$ , and are not included in Table II.) Although some of these calculations could largely account for the larger observed values of  $G$ , the main point is that the theoretical variations are also large.

The study of the  $^{38}\text{Ar}(p,n)^{38}\text{K}$  reaction bears on the question of ground-state correlations in  $^{40}\text{Ca}$ . It was claimed that there is a  $7^+$  state in  $^{38}\text{K}$  at 5.28 MeV that is excited strongly by the  $^{40}\text{Ca}(d,\alpha)^{38}\text{K}$  reaction at 80 MeV [13,14]. The most recent of these measurements, performed by Nann *et al.* [13], presents a strong case for the  $7^+$  assignment; both the cross-section and analyzing-

TABLE I. Proton holes in  $^{40}\text{Ca}$  from Table 2 of Ref. [4].

	( $e, e'$ )	( $^3\text{He}, d$ )	( $d, ^3\text{He}$ )	( $t, \alpha$ )
$N_{p-h} = G$	0.7	0.27–0.40	0.73	0.3

power angular distributions have shapes identical to those observed for  $7^+$  excitations from  $^{50}\text{Ti}$ ,  $^{48}\text{Ca}$ , and  $^{42}\text{Ca}$  targets. There are two problems with this conclusion. First, the strength is such that Nann *et al.* conclude, on the basis of comparison with the spectra from the heavier targets, that there are  $0.90 \pm 0.25$   $f_{7/2}$  protons in  $^{40}\text{Ca}$ ; however, if this conclusion were correct, *all* the shell-model calculations of Table II would be very wrong. The simplest  $7^+$  level in  $^{38}\text{K}$  would involve coupling a  $f_{7/2}$  neutron with a  $f_{7/2}$  proton and, in order to be excited in the ( $d, \alpha$ ) pickup reaction, requires a (4p-4h) component in  $^{40}\text{Ca}$ . [In terms of weak-coupling notation [15], the  $7^+$  level would be  $^{42}\text{Sc}(7^+; 0) \otimes ^{36}\text{Ar}(0^+; 0)$ .] A value of 0.9 for  $f_{7/2}$  protons in  $^{40}\text{Ca}$  implies that  $\gamma^2$ , the strength of the 4p-4h component, is 45%, considerably larger than the largest shell-model prediction tabulated below (viz., 15% in Ref. [7]). If we add  $\gamma^2 = 0.45$  to the lowest experimental value of  $\beta^2 = 0.3$  from Table I (assuming  $N_{p-h} \approx \beta^2$  here), we are left with  $\alpha^2 = 25\%$ , a rather poor showing for a doubly magic nucleus!

The second difficulty with the  $7^+$  assignment for the 5.28 MeV state in  $^{38}\text{K}$  is that there is already an established  $7^+$  state at 3.44 MeV in  $^{38}\text{K}$  [16,17]. This latter state is strongly excited in the  $^{36}\text{Ar}(\alpha, d)^{38}\text{K}$  reaction [17] and is almost certainly mainly  $(\pi f_{7/2} \nu f_{7/2})7^+$  [i.e.,  $^{42}\text{Sc}(7^+) \otimes ^{36}\text{Ar}(0^+)$ ]. The excitation energy of the  $7^+$  state at 3.44 MeV fits in well with the  $A$  dependence observed for this excitation in the  $s$ - $d$  shell [17]. The state at 5.28 MeV was not observed in the ( $\alpha, d$ ) experiment nor the 3.44 MeV level in the ( $d, \alpha$ ) experiment [13], making it hard to see how both levels can have major components of the  $(\pi f_{7/2} \nu f_{7/2})7^+$  coupling [ $^{42}\text{Sc}(7^+) \otimes ^{36}\text{Ar}(0^+)$ ]. A shell-model calculation (see below) for  $^{38}\text{K}$  yields  $7^+$  states at 3.34 and 6.31 MeV, with the lower level having a spectroscopic strength  $S$  larger by a factor  $\sim 5$  in the ( $\alpha, d$ ) reaction—consistent with experiment [17]—and favored by a factor of 6 in the ( $d, \alpha$ ) reaction, completely at variance with observation. A possible resolution of this apparent paradox is that the 5.28 MeV level is a  $6^-$  level, i.e., a  $(f_{7/2}, d_{5/2}^-)$  stretched state which could be generated by ( $d, \alpha$ ) from the appreciable (2p-2h) component of  $^{40}\text{Ca}$ . Simple, semiclassical arguments indicate that the analyzing powers for both  $6^-$  and  $7^+$  excitations should be identical. Indeed, distorted wave Born approximation (DWBA) calculations for a  $6^-$

TABLE II. Ground-state correlations in  $^{40}\text{Ca}$  from shell-model calculations.

	Sakakura [7]	Brown [8]	Zamick [1]	Chaves [9]
$\alpha^2$	0.46	0.72	0.78	$\geq 0.43$
$\beta^2$	0.35	0.24	0.22	
$\gamma^2$	0.15	0.035		
$\beta^2 + 2\gamma^2$	0.65	0.31	0.22	0.57

state yield cross-section and analyzing-power angular distributions that fit the 80 MeV ( $d, \alpha$ ) data of Nann *et al.* equally as well as the  $7^+$  calculations [18]. Note also that such a state could not be excited in the ( $\alpha, d$ ) reaction.

The  $^{38}\text{Ar}(p, n)^{38}\text{K}$  reaction can be used to investigate the structure of these states. The  $6^-$ ,  $1\hbar\omega$  ( $f_{7/2}, d_{5/2}^-$ ) excitation has been observed with the ( $p, n$ ) reaction on  $^{26}\text{Mg}$ ,  $^{28}\text{Si}$ ,  $^{32}\text{S}$ , and  $^{40}\text{Ca}$  [19–22]. The  $7^+$ ,  $0\hbar\omega$  ( $f_{7/2}, f_{7/2}$ ) excitation has been observed with the ( $p, n$ ) reaction on  $^{42}\text{Ca}$ ,  $^{48}\text{Ca}$ , and  $^{54}\text{Fe}$  [23–25]. In all but the  $^{28}\text{Si}$  case, the  $6^-$  strength is fragmented. This fragmentation has been attributed to the fragmentation of the  $d_{5/2}$  hole strength in the target nucleus [21,22], and one might expect this to be the case for  $^{38}\text{Ar}$  as well. The  $7^+$  strength observed in the  $f$ - $p$  shell nuclei is generally concentrated in one state at low excitation energy.

In this paper, we report the results of measurements of the  $^{38}\text{Ar}(p, n)^{38}\text{K}$  reaction at 135 MeV. The states of interest discussed above are observed and their angular distributions compared with DWIA calculations. The observed strength is compared with shell-model predictions and the earlier ( $d, \alpha$ ) results. While definitive conclusions are not possible, we find that it is plausible that the state at 5.28 MeV in  $^{38}\text{K}$  is a  $6^-$  state and that there is no evidence for a major breakdown of the shell model.

## II. EXPERIMENTAL PROCEDURE

The experiment was performed at the Indiana University Cyclotron Facility (IUCF) with the beam-swinging system. The experimental arrangement and data-reduction procedures were similar to those described previously [19,24]. Neutron kinetic energies were measured by the time-of-flight (TOF) technique. A beam of 135 MeV protons was obtained from the cyclotron in narrow beam bursts typically 350 ps long, separated by  $\sim 2$   $\mu\text{s}$ . The long time between beam bursts was obtained by use of a small storage ring between the beam source and the main cyclotron, referred to as the “stripper loop.” This long time between bursts eliminates “overlap” background from previous beam bursts and greatly reduces the cosmic-ray background as well. Neutrons were detected in three detector stations at  $0^\circ$ ,  $24^\circ$ , and  $45^\circ$  with respect to the undeflected proton beam. The flight paths were 131.0, 130.2, and 81.4 m ( $\pm 0.2$  m), respectively. The neutron detectors were rectangular bars of fast plastic scintillator, 10.2 cm thick. Three separate detectors each with a scintillator bar 1.02 m long by 0.51 m high were combined for a total frontal area of 1.55  $\text{m}^2$  in the  $0^\circ$  and  $24^\circ$  stations. Two detectors were used in the  $45^\circ$  station, both with a scintillator bar 1.52 m long by 0.76 m high, for a combined frontal area of 2.31  $\text{m}^2$ . Each neutron detector had tapered Plexiglas light pipes attached on the two ends of the scintillator bar, coupled to 12.76-cm-diameter phototubes. Timing signals were derived from each end and combined in a meantimer circuit [26] to provide the timing signal from each detector. Overall time resolutions of about 825 ps were obtained, including contributions from the beam burst width ( $\sim 350$  ps) and energy spread ( $\sim 400$  ps), energy loss in the target ( $\sim 460$  ps), neutron transit times across the 10.2 cm thickness of

the detectors ( $\sim 530$  ps), and the intrinsic time dispersion of each detector ( $\sim 300$  ps). This overall time resolution provided an energy resolution of about 320 keV in the first two detector stations and about 450 keV in the widest-angle station. The large-volume neutron detectors were described in more detail previously [27]. Protons from the target were rejected by anticoincidence detectors in front of each neutron detector array. Cosmic rays were vetoed by anticoincidence detectors on top as well as the ones in front of each array.

The target was a low-volume cylindrical gas cell 4 cm long by 1 cm diameter. The entrance and exit windows were 2 mil Kapton. The cell was filled to  $\sim 3$  atm absolute with  $^{38}\text{Ar}$  gas, enriched to 95%. Empty-cell runs were performed to subtract contributions for the Kapton windows. Time-of-flight spectra were obtained at 15 angles between  $0^\circ$  and  $63^\circ$ . Spectra from each detector were recorded at many pulse-height thresholds from 25 to 90 MeV equivalent-electron energy (MeVee). Calibration of the pulse-height response of each of the detectors was performed with a  $^{228}\text{Th}$  gamma source ( $E_\gamma = 2.61$  MeV) and a calibrated fast amplifier. The values of the cross sections extracted for different thresholds were found to be the same within statistics.

### III. DATA REDUCTION

Excitation-energy spectra were obtained from the measured TOF spectra using the known flight paths and a calibration of the time-to-amplitude converter. The  $^{12}\text{C}(p,n)^{12}\text{N}$  reaction from carbon in the Kapton gas-cell windows was used to provide absolute reference points (see Fig. 1). At forward angles, the  $^{12}\text{C}(p,n)^{12}\text{N}(1^+, \text{g.s.})$  transition was used; at wide angles, the  $^{12}\text{C}(p,n)^{12}\text{N}(4^-, 4.3 \text{ MeV})$  transition was employed. This procedure is estimated to yield absolute neutron kinetic energies (and therefore excitation energies) good to  $\pm 0.1$  MeV.

In order to obtain excitation-energy spectra for the  $^{38}\text{Ar}(p,n)^{38}\text{K}$  reaction, it was necessary to subtract the contributions from the Kapton entrance and exit windows of the gas cell. This was performed in the TOF

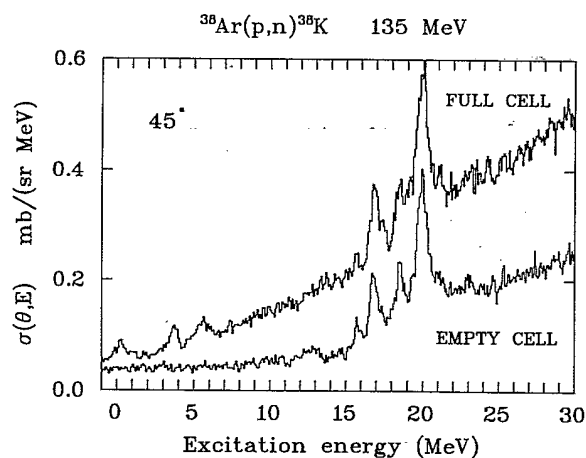


FIG. 1. Full-cell and empty-cell excitation-energy spectra. The large peaks seen in the empty-cell spectra are from the carbon, nitrogen, and oxygen in the Kapton entrance and exit windows.

spectra by subtracting empty-cell runs. The TOF spectra were aligned using the strong  $^{12}\text{C}(p,n)^{12}\text{N}$  peaks. The empty-cell run was normalized to the full-cell run by comparing yields in the  $^{12}\text{C}(p,n)$  peaks. Because there is additional energy loss in the  $^{38}\text{Ar}$  gas for a full-cell run, it was observed that the peaks in an empty-cell run were somewhat narrower than for a full-cell run. This difference produced positive and negative swinging oscillations for subtractions of peaks, even when properly normalized. This problem was eliminated (to first order) by performing a Gaussian smearing of the empty-cell runs to broaden the TOF peaks. The full and empty-cell runs at  $45^\circ$  (converted to excitation-energy spectra) are shown in Fig. 1. Strong peaks from the carbon and oxygen in the Kapton windows are present between 15 and 22 MeV of excitation. The primary region of interest for this work is from 0 to 10 MeV of excitation, where the (smaller) peaks from the  $^{38}\text{Ar}(p,n)^{38}\text{K}$  reaction are observed in the full-cell run. The difference spectrum is shown in Fig. 2. The subtraction procedure yields significant statistical fluctuations above about 10 MeV of excitation. The narrow spike observed near 20 MeV is probably from imperfect subtraction of the strong  $4^-$  transition in the  $^{12}\text{C}(p,n)$  reaction.

Yields for transitions in the  $^{38}\text{Ar}(p,n)^{38}\text{K}$  reaction were obtained by peak fitting of the TOF spectra. The spectra were fitted with an improved version of the Gaussian peak-fitting code of Bevington [28]. Examples of peak fitting of similar  $(p,n)$  neutron TOF spectra were presented earlier [24,25]. Cross sections were obtained by combining the yields with the measured geometrical parameters, the beam integration, and the target thickness. The neutron detector efficiencies were obtained from a Monte Carlo computer code [29], which was tested extensively at these energies [30,31]. The overall absolute cross sections were checked by remeasuring the known  $^{12}\text{C}(p,n)^{12}\text{N}(\text{g.s.})$  cross section with a carbon-foil target. The experimental procedure and data reduction are similar to that described in more detail in Refs. [19] and [24]. The uncertainty in the overall scale factor is dominated by the uncertainty in the detector efficiencies and is estimated to be  $\pm 12\%$ .

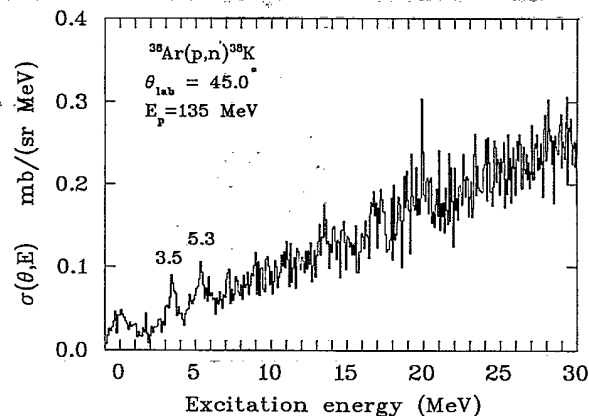


FIG. 2.  $^{38}\text{Ar}(p,n)^{38}\text{K}$  excitation-energy spectrum at 135 MeV and  $45^\circ$ . The large statistical fluctuations at increasing excitation energy are from the empty-cell subtraction (see Fig. 1).

## IV. RESULTS AND DISCUSSION

An excitation-energy spectrum for the  $^{38}\text{Ar}(p,n)^{38}\text{K}$  reaction at  $45^\circ$  is shown in Fig. 2. The two transitions of most interest here are to states at 3.5 and 5.3 MeV of excitation. These transitions can be seen clearly in Fig. 2. The extracted angular distributions for these two transitions, plus that for the "shoulder" at  $E_x = 5.9$  MeV on the side of the 5.3 MeV peak, are shown in Fig. 3.

As discussed above, the question of interest here concerns the nature of the state at 5.3 MeV. To this end, we compare in Fig. 3 the angular distributions with DWIA calculations for a transition to a  $6^-$  or  $7^+$  state. The DWIA calculations were performed with the code DW81 [32], with the nucleon-nucleon effective interaction of Franey and Love [33] and optical-model parameters taken from the global set of Schwandt *et al.* [34]. For the  $6^-$  calculation, the final state is assumed to be pure  $(\pi f_{7/2}, \nu d_{5/2}^{-1})$  and the initial (target) state to have a full  $d_{5/2}$  neutron orbital and an empty  $f_{7/2}$  proton orbital. For the  $7^+$  calculation, the final state is assumed to be pure  $(\pi f_{7/2}, \nu f_{7/2}^{-1})$  and the initial state to have a full  $f_{7/2}$  neutron orbital and an empty  $f_{7/2}$  proton orbital. Harmonic oscillator wave functions were assumed with an oscillator parameter of  $b = 1.86$  fm. The required DWIA normalization factors are referred to as  $Z^2$  coefficients and are indicated for each case; these  $Z^2$  values can be compared directly with shell-model predictions as described below.

The transitions of interest are clearly part of un-

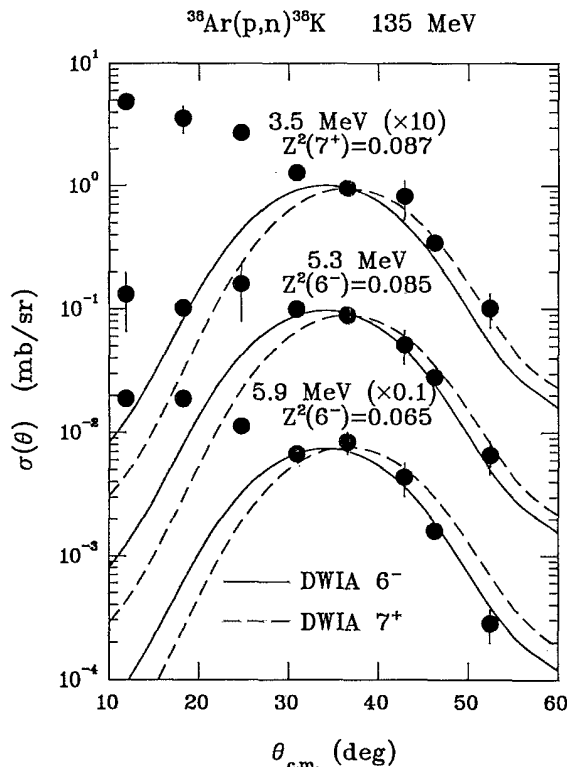


FIG. 3. Angular distributions for the  $^{38}\text{Ar}(p,n)^{38}\text{K}$  reaction at 135 MeV to the complexes at 3.5, 5.3, and 5.9 MeV. The lines represent DWIA calculations (see text).

resolved complexes including lower-spin states that cause the experimental cross sections to continue to rise at smaller angles. The DWIA calculations were fit to the widest-angle points. Earlier analyses for high-spin "stretched" states in other nuclei indicate that the contributions from the lower-spin states are negligible beyond about  $40^\circ$ . As shown in Fig. 3, it is impossible to make unambiguous decisions regarding which calculations fit the experimental angular distributions better. For the 3.5 MeV transition, the  $7^+$  calculation fits somewhat better and the 5.9 MeV transition is fit better by a  $6^-$  calculation. For the 5.3 MeV transition, either calculation describes the data reasonably well.

For further assistance in trying to identify these states in  $^{38}\text{K}$ , we compare the observed excitation-energy spectrum with that predicted by shell-model calculations. The results of such calculations are shown in Fig. 4, compared with a "smoothed" excitation-energy spectrum at  $45^\circ$ . This smoothing was performed to try to see any further structure in the excitation-energy region above 10 MeV, where the statistical fluctuations are severe. The shell-model calculations were performed with the computer code OXBASH [35]. The  $0^+$  to  $7^+$  calculation assumes the full  $(1d_{3/2}, 1f_{7/2})$  model space and uses the SAS (Sakakura-Arima-Sebe) interaction [7]. The  $0^+$  to  $6^-$  calculation assumes 0-hole (0h) to one-particle-three-hole (1p-3h) in the *sdpf* model space and

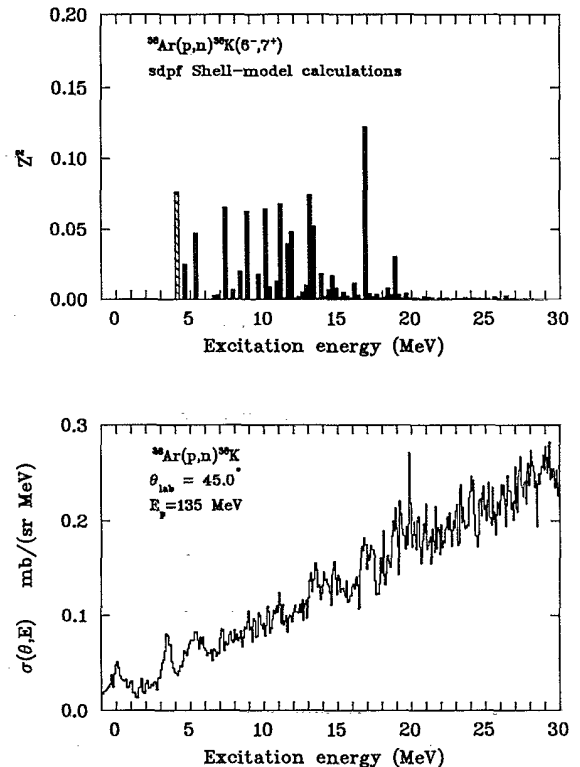


FIG. 4. Comparison of DWIA calculations for the excitation of  $6^-$  (solid bars) and  $7^+$  (cross-hatched bar) stretched states in the  $^{38}\text{Ar}(p,n)^{38}\text{K}$  reaction at 135 MeV with the smoothed excitation-energy spectrum at  $45^\circ$ . The DWIA calculations use *sdpf* shell-model wave functions described in the text. The theoretical strengths are in units of  $Z^2$  (see text).

uses an interaction which is a combination of Wildenthal's interaction for the  $s$ - $d$  shell [36], plus McGrory's interaction for the  $f$ - $p$  shell [37]. The one-body transition densities obtained from these calculations were converted to  $Z$  coefficients and their squares plotted in Fig. 4.

The predicted  $7^+$  and  $6^-$  spectra taken together actually reproduce the observed spectrum fairly well. One possible explanation of the observed spectrum is that the lowest state, at 3.5 MeV, is the low-lying  $7^+$  state predicted to be at 3.9 MeV, and the states observed at 5.3 and 5.9 MeV are the  $6^-$  states predicted near 5 MeV. The smoothed experimental excitation-energy spectrum appears to show some additional strength above 5 MeV, especially between 13 and 20 MeV, which could be some of the predicted higher-lying  $6^-$  strength.

It is interesting also to note that the  $Z^2$  obtained from the DWIA fits (see Fig. 3) and those predicted with the shell-model calculations are quite comparable; for example, the  $Z^2$  obtained from the  $7^+$  fit to the 3.5 MeV state is 0.068, while the shell-model calculation predicts 0.076 for the lowest  $7^+$  state. Similarly, the "experimental"  $Z^2$  for the 5.3 MeV state is 0.085, assuming it is  $6^-$ , while the shell-model calculations predict states with  $Z^2$  from 0.05 to 0.08 between 5 and 10 MeV. Considered this way, there is no obvious problem with the observed spectrum compared with the shell-model predictions.

## V. CONCLUSIONS

The  $^{38}\text{Ar}(p,n)^{38}\text{K}$  reaction at 135 MeV was studied at large-momentum transfer to search for  $6^-$  and  $7^+$  stretched-state excitations. States at 3.5, 5.3, and 5.9 MeV were observed and their angular distributions compared with DWIA calculations for  $(f_{7/2}, d_{5/2}^{-1})6^-$  and  $(f_{7/2}, f_{7/2}^{-1})7^+$  excitations. The angular distributions for these states can be described by either of these calculations, although the 3.5 MeV state is described somewhat better by a  $7^+$  calculation and the 5.9 MeV state by a  $6^-$  calculation. The observed excitation-energy spectrum at  $45^\circ$  was compared with large-basis shell-model calculations for  $6^-$  and  $7^+$  strength. This comparison would suggest that the lowest state, at 3.5 MeV, is plausibly a

$7^+$  state and the states at 5.3 and 5.9 MeV are  $6^-$  states. This interpretation is consistent with earlier identification of the 3.5 MeV state as  $7^+$ , but is not consistent with the analysis [13,14] of  $^{40}\text{Ca}(d,\alpha)^{38}\text{K}$  measurement at 80 MeV which claim that there is a  $7^+$  state at 5.3 MeV. This assignment was interpreted in our Introduction as a major problem for the nuclear shell model, because very large  $^{40}\text{Ca}$  ground-state correlations would be required to explain this conclusion. The  $^{38}\text{Ar}(p,n)^{38}\text{K}$  results presented here are in reasonable agreement with  $sdpf$  large-basis shell-model calculations and show no evidence for a significant problem with the nuclear shell model for  $A=38$ .

It is still of interest to ascertain the structure of the 5.28 MeV level observed in the high-energy  $(d,\alpha)$  experiments. Such a level has not been identified in low-energy deuteron measurements at 16–28 MeV [38], nor has the 3.458  $7^+$  level, but at these energies the momentum transfer may be too low to excite a high-spin state, which the 5.28 MeV state must be.

Could this level be the  $6^-$  state seen here at 5.3 MeV? The same shell-model parameters used to compute the  $(p,n)$  strengths in Fig. 4 were used to compute the  $6^-$  strengths to be seen in the  $^{40}\text{Ca}(d,\alpha)$  reaction. The result was that the 5.3 and 5.9 MeV states of the  $(p,n)$  spectra should have been equally strong in  $(d,\alpha)$  whereas only a 5.3 MeV peak is seen in Refs. [13] and [14]. Furthermore, three peaks, each twice as strong, should have been seen at  $\sim 8, 10,$  and  $11$  MeV, contrary to the observations of Nann *et al.* [13].

A spin of  $9^+$  has been tentatively assigned to a level at 5.25 MeV by van der Poel *et al.* [16]. This state decays to the  $7^+$  level at 3.458 MeV. As the latter is a  $35 \mu\text{s}$  isomer, a measurement of the  $\gamma$  decay of the  $(d,\alpha)$  level at 5.28 MeV would unambiguously determine the identity of the two states. Aside from such a  $(d,\alpha\gamma\gamma_{\text{delayed}})$  experiment at 80 MeV, another interesting experiment would be an 80 MeV  $(\bar{d},\alpha)$  measurement [39] of  $T_{20}$  near  $0^\circ$  to determine whether the 5.28 MeV state has natural or unnatural parity.

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