THE $^{40}Ar(\tau, n)^{42}Ca$ REACTION ☆

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The results of an investigation of the $^{40}Ar(\tau, n)^{42}Ca$ reaction at 18.65 MeV incident energy are reported. The weakness of the transition to the 1.84 MeV 0^+ level is in disagreement with 4p–2h descriptions of this state.

The energy spectrum of ^{42}Ca is known to contain low-lying states which cannot be described by the two valence neutrons in the $1f_{7/2}$ shell alone. The extra 0^+ and 2^+ states at 1.84 and 2.42 MeV, respectively, have been attributed to 4p–2h states [1–4], with the four particles (two protons and two neutrons) assumed to be in a low-lying deformed state projected from the # 14 Nilsson orbital. Such models have been relatively sucessful in reproducing the energy spectrum [1–4], electromagnetic transition rates [1–3], and relative cross sections for the (t, p) reaction leading to ^{42}Ca [4]. In particular, the (t, p) cross section to the 1.84 MeV 0^+state is predicted to be only 16% of that to the ground state [4], in reasonable agreement with experiment [5].

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In an attempt to verify the nature of these extra levels in ^{42}Ca, the $^{40}Ar(\tau, n)^{42}Ca$ reaction has been studied using The University of Michigan neutron time-of-flight spectrometer [6]. Measurements were made at eight angles with an 18.65 MeV ^3He beam incident on a natural gas target. A typical neutron time-of-flight spectrum is shown in fig. 1. The striking feature of the spectrum is the absence of strongly excited levels. The differential cross section for the ground state was found to be peaked at 0° with a peak cross section of 810 ± 170 μb/sr. While there are indications of transitions corresponding to known states and also to states between 8 and 10 MeV (in the 0° spectrum), none has a cross section larger than 80 μb/sr. The data at 0° and 15° are summarized in table 1. Because the levels at high excitation are not

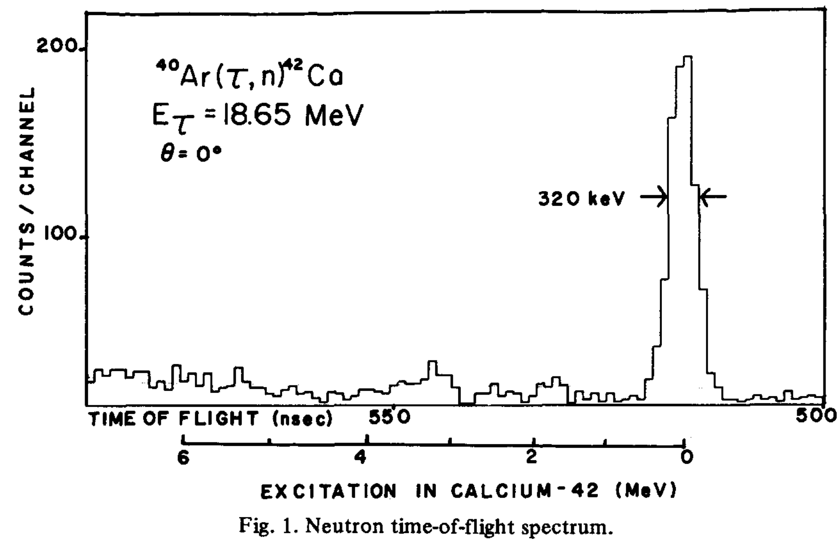

Fig. 1. Neutron time-of-flight spectrum.

Table 1
Differential cross sections for the $^{40}Ar(\tau, n)^{42}Ca$ reaction at $E_\tau = 18.65$ MeV. The errors in the cross section (ranging from 20% for the strongest to 75% for the weakest group) include a 20% systematic error as well as the statistical error.

$E_x(^{42}Ca)$ (MeV)	J^π	dσ/dΩ (μb/sr) 0°	15°
0	0^+	810	90
1.52	2^+	< 20	40
1.84	0^+	40	< 20
2.42	2^+	30	40
3.4	2^+	50	50
3.7	2^+	30	30

seen at larger angles, they may be 0^+ states. The peak near 3.4 MeV is assumed to be due mainly to the known 2^+ state because the measured cross sections at 0° and 15° are comparable. A 0^+ state at 3.3 MeV has been reported recently to have been observed in the $^{38}Ar(^6Li, d)^{42}Ca$ reaction [7]. While not resolved in the spectra of fig. 1, the cross section would appear to be less than 50 μb/sr. It is worth noting that because of the high Q-value of the (τ, n) reaction (+10.36 MeV), states due to likely contaminants will not appear in the first 10 MeV of excitation. This was verified by background measurements taken with the gas cell evacuated.

The data show that the transition to the 1.85 MeV 0^+ state is a factor of twenty weaker than that to the ground state. To indicate that it is impossible to understand this result in terms of the simplest interpretations of the 4p–2h state, several DWBA calculations using standard optical model parameters [8] have been performed with the two-nucleon transfer option of the code DWUCK [9]. The predicted cross sections for the 1.84 MeV state relative to the ground state are given in table 2 as are the wave functions assumed for the proton pair. The simplest shell model calculations for ^{38}Ar give a ground-state configuration [10] which is 95% $(1d_{3/2})^{-2}$ and 5% $(2s_{1/2})^{-2}$. In the calculation for set 1, the protons transferred to the ground state were assumed to simply fill this two-hole state. The 1.84 MeV state was assumed to be a pure $(1f_{7/2})^4$ $J_p = 0$, $T_p = 0$ four-particle configuration coupled to the ^{38}Ar core, so that the transferred protons were assumed to be a $(1f_{7/2})^2$ pair. For the second set the spherical two-particle shell model state was mixed with theoretical predictions [1–4]. The amplitudes were chosen so that the transferred $L = 0$ proton pair gives constructive coherence for the ground state, while the 1.84 MeV state was the orthogonal combination. For the third set, a more realistic deformed state configuration was used. Using the Nilsson coefficients given by Barz et al. [4], their prescription for the construction of the projected two-particle $J = 0$ deformed state was followed. The resulting state was then mixed with the shell model s-d state in accordance with their ^{42}Ca wave functions. The calculations were made assuming that the transfer of the proton pairs reflected these configurations. It should be noted that the ratios given in table 2 do not account for the overlaps of the spherical valence neutrons in ^{40}Ar with the neutron pair in the final deformed state in ^{42}Ca. However, for the 1.84 MeV state wave function of Barz et al. [4] this overlap is 0.95, thus

Table 2
Wave functions for the transferred proton pair and resulting relative cross sections.

	Set 1		Set 2		Set 3	
	0^+ g.s.	0^+ 1.84 MeV	0^+ g.s.	0^+ 1.84 MeV	0^+ g.s.	0^+ 1.84 MeV
$(2s_{1/2})^2$	0.224		0.200	0.104	0.199	0.102
$(1d_{3/2})^2$	0.975		0.863	0.453	0.667	0.445
$(1f_{7/2})^2$		1.0	−0.465	0.885	−0.410	0.801
$(2p_{3/2})^2$					−0.195	0.380
$(1f_{5/2})^2$					−0.012	0.023
$(2p_{1/2})^2$					−0.038	0.075
cross section ratio 0^+1.84 MeV/0^+g.s.	1.8		0.23		1.3	

the cross-section ratio will only be changed by at most 5%.

All three calculations seriously overestimate the 1.84 MeV 0^+ strength. The results of the calculations are due in large part to the preference for the transfer of a $(1f_{7/2})^2$ pair over the transfer of a $(1d_{3/2})^2$ pair. This preference is seen experimentally in the analogous two-neutron transfer reactions. Casten et al. [10] report a cross section of 470 μb/sr for the ground state transition in the reaction ^{36}Ar(t, p)^{38}Ar (primarily $1d_{3/2}^2$ transfer), compared with a cross section of 820 μb/sr for the ground state in the ^{40}Ca(t, p)^{42}Ca reaction (mainly $1f_{7/2}^2$ transfer).

Although the calculations reported here represent the most naive application of the theoretical treatments of ^{42}Ca, the discrepancy between the calculation and the data is thought to be severe enough to warrant a reevaluation of the structure of the 1.84 MeV 0^+ state.

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