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CONFIGURATION OF 3.59 MeV 0^+ STATE IN ^{44}Ca

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Results obtained with the ^{48}Ti(d, ^{6}Li) reaction, at E_d = 55 MeV, establish the 3.59 MeV 0^+ level of ^{44}Ca as virtually pure 8 p–4h, with T_h = 0.

The importance of core-excited configurations even at low excitation energies in the Ca isotopes has been recognized for a long time (see ref. [1] for a summary of the relevant references). For example, the presence [2,3] of low-lying 0^+ states in ^{40,42,44}Ca (depicted in fig. 1) can be explained only by inclusion [4] of excitations out of the sd-shell. Shell-model calculations [5,6] that assume an inert sd-shell core do not contain them. In ^{40}Ca, it appears [4,7,8] that the 3.35 MeV 0^+ state is dominantly of four particle-four hole (4p–4h) character. In ^{42}Ca and ^{44}Ca, the presence of two low-lying excited 0^+ states in each nucleus demands the presence of two core-excited components in each: 4p–2h and 6p–4h in ^{42}Ca, and presumably 6p–2h and 8p–4h in ^{44}Ca.

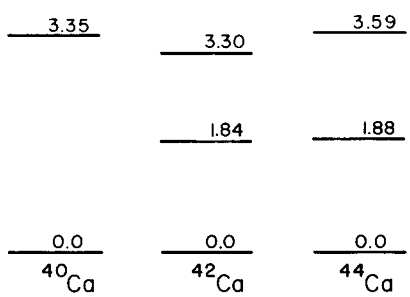

Fig. 1. Low-lying 0^+ levels in ^{40,42,44}Ca.

In ^{42}Ca the first three 0^+ states have been described [1,9] as linear combinations of the configurations $(\mathrm{fp})^2_{01}$, $(\mathrm{fp})^{-2}_{01}$, and $(\mathrm{fp})^6_{01}(\mathrm{sd})^{-4}_{00}$, where the double subscripts denote JT. This model gives a good account [1,9,10] of the available data, especially of the fact that the third 0^+ level of ^{42}Ca (at 3.30 MeV) is strong in α-stripping [3]. The resulting wave functions for ^{42}Ca [9] are strongly mixed, with the second and third 0^+ states containing comparable components of 4p–2h and 6p–4h configurations.

In ^{44}Ca, the situation is qualitatively different. Although the second 0^+ state has a (^{6}Li, d) cross section [22] (relative to the g.s.) very nearly equal to that measured in ^{42}Ca, viz. $\sigma(1.88)/\sigma(\mathrm{g.s.}) = 0.2$, the third 0^+ level of ^{44}Ca is completely absent in ^{40}Ar (^{6}Li, d): $\sigma(3.59)/\sigma(\mathrm{g.s.}) = 0.015$ [11]. This is to be compared with $\sigma(3.30)/\sigma(\mathrm{g.s.}) = 0.8$ in ^{42}Ca [3]. This result has been suggested [1,11] to imply that configuration mixing is less severe in ^{44}Ca than in ^{42}Ca and that the third 0^+ level of ^{44}Ca probably contains very little 4p or 6p–2h structure.

This interpretation is consistent with the fact that the 3.59 MeV 0^+ level of ^{44}Ca is extremely weak in all transfer reactions that have been studied, including ^{43}Ca(d, p) [12], ^{42}Ca(t, p) [13], ^{40}Ar(^{6}Li, d) [11], ^{45}Sc(d, ^{3}He) [14] and ^{45}Sc(t, α) [15]. All these data are consistent with the assumption that the g.s. and

1.88 MeV states have mixed 4p and 6p–2h configurations, with the 3.59 MeV level having a relatively pure wave function of more complicated structure.

Since the 3.59 MeV state is so weak in all the above reactions, those reactions yield no definite information concerning this structure, other than the fact that it is more complicated than 6p–2h. The two most likely possibilities are both 8p–4h, one with the holes having $T = 0$, the other with the particles coupled to $T = 0$, i.e. $(fp)^8_{02}(sd)^{-4}_{00}$ or $(fp)^8_{00}(sd)^{-4}_{02}$. In weak-coupling terms these are $^{48}Ti \otimes ^{36}Ar$ and $^{48}Cr \otimes ^{36}S$, respectively. From the masses, both could lie quite low in ^{44}Ca.

The $^{48}Ti(d, ^6Li)$ reaction provides a very sensitive means of choosing between the two 8p–4h configurations listed above, since a state of the type $^{48}Ti \otimes ^{36}Ar$ can be easily made in α-pickup from ^{48}Ti, whereas population of a state of the form $^{48}Cr \otimes ^{36}S$ is strongly forbidden. An earlier study [16] of the $^{48}Ti(d, ^6Li)$ reaction investigated only states below 2 MeV excitation.

We have performed the $^{48}Ti(d, ^6Li)^{44}Ca$ reaction with a 55 MeV deuteron beam from the K.V.I. cyclotron. The target was a selfsupporting foil of ^{48}Ti (enriched $>$ 96.5%). Its thickness was obtained by measuring the energy loss in the target for 5.5 MeV α particles. The estimated thickness of ^{48}Ti in the target was 210 μg/cm^2 (±20%). The large error in the target thickness determination is mainly due to the ^{12}C and ^{16}O contaminants in the target whose thicknesses were estimated from their contributions in the present experiment. Outgoing ^6Li ions were momentum analyzed in the QMG/2 magnetic spectrograph of the K.V.I. Particles were detected in a gas-filled position-sensitive detector system placed along the focal plane. A full description of the detection system will be given elsewhere [17]. Briefly it provides measurement of horizontal and vertical position, horizontal and vertical angle of incidence, $\Delta E/\Delta x$, E (in a plastic scintillator) and t (the time relative to a cyclotron beam burst). The detection and identification of ^6Li ions can be made quite unambiguously with this setup.

The octogonal entrance slits of the spectrograph were set to subtend a horizontal-angle span of 4.9° and a vertical-angle range of 5.6°. Total solid angle was 8.3 msr. Typical spectra are displayed in fig. 2. One setting of the magnetic field of the spectrograph covers about 3 MeV in excitation energy. Thus data were obtained for two different settings. A number of peaks present in both settings provided a check on the relative normalizations. The resolution of 80 keV is determined

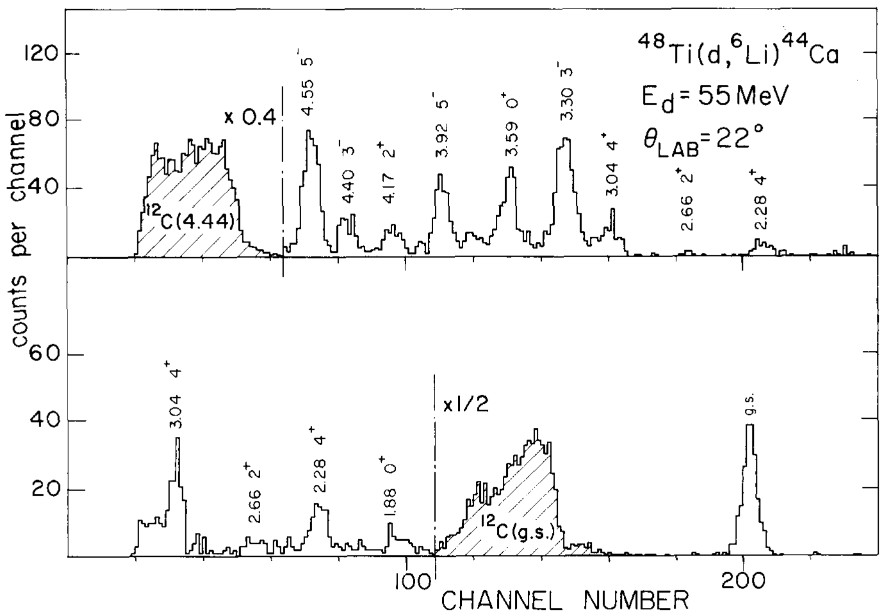

Fig. 2. Spectra from the $^{48}Ti(d, ^6Li)^{44}Ca$ reaction at E_d = 55 MeV and θ (lab) = 22°.

almost exclusively by the target thickness.

Angular distributions for the three 0^+ levels of interest are displayed in fig. 3. The 1.88 MeV state is quite weak and obscured by an impurity peak at forward angles, but the present results are consistent with ref. [16] for this state. The 3.59 MeV state is strong and has a clear L = 0 angular distribution. The curves in the figure are the results of zero-range DWBA calculations using the code DWUCK [18] and the optical-model parameters [19, 20] listed in table 1. These potentials have been used previously [21] in fitting (d, ^{6}Li) data at the same bombarding energy.

Relative spectroscopic factors extracted from the present data (normalized to unity for the g.s.) are listed in table 2. For the 3.59 MeV state, the large value of S_α measured in this experiment, together with the very small S_α in stripping, provides proof that its configuration is indeed dominantly $(fp)^8_{02}(sd)^{-4}_{00}$.

A somewhat more quantitative analysis can be made if we ignore the 8p–4h configuration for the first two 0^+ states, and take 4p amplitudes for them from ^{43}Ca(d, p). Relative spectroscopic factors for both α-stripping and pickup (table 2) are then in quite good agreement with experiment. Thus, all the data are consistent with a virtually $(fp)^8_{00}(sd)^{-4}_{00}$ structure for the 3.59 MeV 0^+ level of ^{44}Ca.

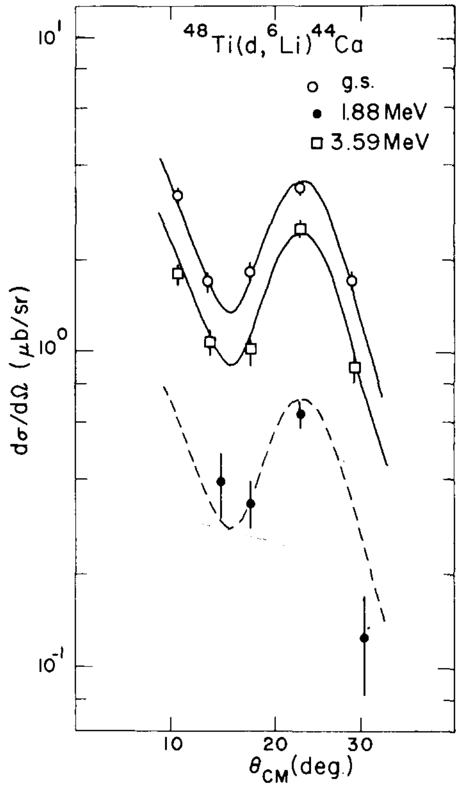

Fig. 3. Angular distributions for the ^{48}Ti(d, ^{6}Li) reaction leading to the first three 0^+ states of ^{44}Ca. Curves are from DWBA calculations.

Table 1. Optical-model parameters for ^{48}Ti(d, ^{6}Li)^{44}Ca. Potentials in MeV, lengths in fm.

	V	r_0	a	W	$W' = 4W_D$	r'_0	a'	r_{0c}
d [a]	91.25	1.05	0.87	0	52.0	1.28	0.79	1.30
^{6}Li [b]	234.7	1.30	0.70	15.0	0	1.70	0.90	1.30
α	–	1.45	0.60	–	–	–	–	1.45

a) Ref. [20]. b) Ref. [19].

Table 2. Measured and calculated relative spectroscopic factors for neutron stripping and α-stripping and pickup leading to 0^+ levels of ^{44}Ca.

E_x(MeV)	n-Stripping		α-Stripping		α-Pickup	
	Exp. [b]	Calc.	Exp. [c]	Calc.	Exp. [d]	Calc.
0 [a]	1.0	1.0	1.0	1.0	1.0	1.0
1.88	0.20	0.20	0.20	0.14	0.13	0.14
3.59	~0	0	<0.015	0	0.55	0.57

a) All spectroscopic factors normalized to unity for the g.s. b) Ref. [12]. c) Ref. [11]. d) Present work.

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