High-spin yrast levels in ^{39}Ar†

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Fusion-evaporation reactions induced by ^{18}O bombardment of ^{24}Mg, ^{26}Mg, and ^{27}Al targets with projectile energies of 20-60 MeV were used to populate high-spin states in ^{39}Ar. Our results suggest assignments of $\frac{11}{2}^-$, $\frac{13}{2}^+$, $\frac{15}{2}^+$, and $\frac{17}{2}$ for ^{39}Ar levels at 2651, 3992, 4543, and 5536 keV, respectively. The excitation energies of these presumed yrast levels are compared to weak-coupling predictions.

[NUCLEAR REACTIONS ^{24}Mg(^{18}O, $2pn\gamma$), ^{26}Mg(^{18}O, $\alpha n\gamma$), ^{27}Al(^{18}O, $\alpha pn\gamma$), E=20-60 MeV; measured γ-γ coin; deduced levels in ^{39}Ar; measured $\sigma(E_\gamma, \theta)$ and P_γ; deduced J^π for high-spin levels; measured Doppler shift; deduced τ, $|M(ML)|^2$. Enriched targets, Ge(Li) detectors.]

The results on ^{39}Ar contained herein were obtained in the course of a general investigation of high-spin states in nuclei near $A = 40$. A brief report[1] of these ^{39}Ar results has been given previously and much of the relevant data has been published in tabular form.[2,3]

The first evidence for formation of ^{39}Ar was encountered in $\gamma-\gamma$ coincidence data taken for ^{18}O + ^{26}Mg (Refs. 4 and 5) which showed clear and definite evidence for a cascade of four γ rays with energies of 992, 551, 1341, and 2651 keV. Subsequently, evidence for this cascade scheme was also observed in $\gamma-\gamma$ coincidence data for ^{18}O + ^{24}Mg and ^{18}O + ^{27}Al. The assignment of these γ rays to ^{39}Ar is based on excitation functions for 11 projectile-target combinations.[6] The cascade γ rays were observed in six of these combinations with varying relative intensities and excitation functions but not in the other five. From known systematics[2] of fusion-evaporation reactions—systematics which are quite well understood theoretically[7]—it was possible to make a unique assignment of the cascade to ^{39}Ar.

At 40-MeV bombarding energy the four γ rays were most strongly produced via ^{24}Mg(^{18}O, $2pn\gamma$), ^{26}Mg(^{18}O, $\alpha n\gamma$), and ^{27}Al(^{18}O, $\alpha pn\gamma$) in that order.

TABLE I. ^{39}Ar γ-ray angular distribution and linear polarization results.

γ-ray energy (keV)	Reaction [a]	Relative [b] intensity	Angular [c] distribution (%) A_2	A_4	Linear polarization (%) Exp.	Predicted [d]
992	1	6122	···	···	···	···
	3	3472	···	···	···	···
	4	3322	−21(17)	0	···	···
551	1	7141	−35(2)	−2(3)	−35(8)	−46(4)
	3	9443	−23(5)	−4(6)	−22(7)	−33(9)
	4	6917	−28(5)	0	−44(11)	−36(7)
1341	1	13 785	−22(4)	3(3)	33(16)	−27(7)
	3	18 321	−27(3)	0	15(11)	−35(5)
	4	19 786	−23(2)	0	40(25)	−30(4)
2651	1	15 462	34(3)	−4(3)	68(42)	59(8)
	3	26 340	19(3)	−11(3)	10(26)	25(7)
	4	26 099	23(3)	−7(3)	50(40)	35(8)

[a] Key: ^{18}O + ^{24}Mg(1); ^{18}O + ^{26}Mg(3); ^{18}O + ^{27}Al(4).

[b] Corrected for detector efficiency. Yields for the three different reactions are not relative to each other.

[c] An entry for A_4 of zero is listed when the inclusion of a term in $P_4(\theta)$ does not improve the fit.

[d] Assuming pure $M1$ or $E2$ radiation, and the listed A_2 and A_4 coefficients. The opposite sign pertains for pure $E1$ or $M2$ radiation.

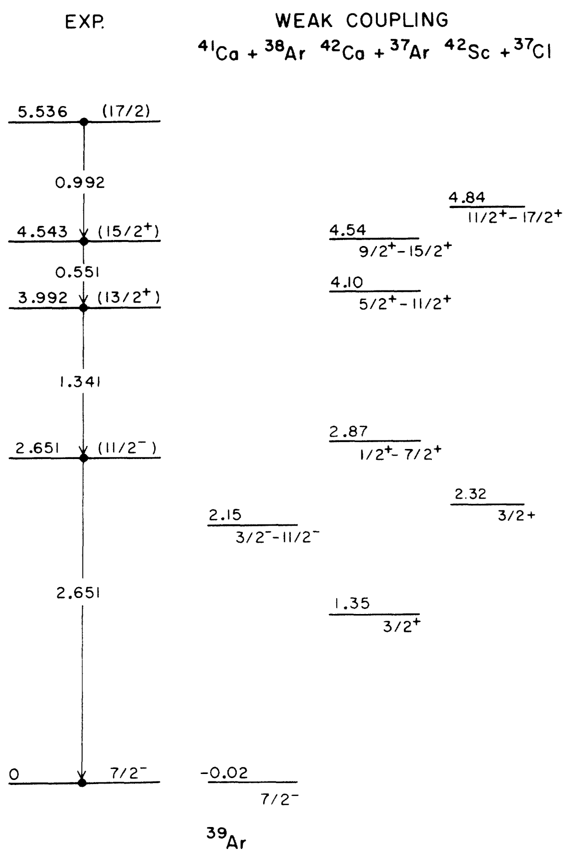

FIG. 1. Energy levels of ^{39}Ar. Energies are in MeV. The experimental spectrum of yrast states on the left is based on the present work and is discussed in the text. The weak-coupling predictions use the parameters [defined by Bansal and French (Ref. 12)] $a = -0.25$ MeV, $b = 2.5$ MeV, and $c = -0.5$ MeV.

The angular distribution[2,8] and polarization[3] data obtained from these three reactions is given in Table I and the decay scheme deduced from this information is shown in Fig. 1. Note that the ordering of the γ rays is definitely established by their relative intensities. The 992-keV γ ray was obscured by a weaker 992-keV line from Coulomb excitation of ^{64}Zn and its analysis was also obfuscated by a strong Doppler effect.

All four γ rays showed partial Doppler shifts in the angular distribution data.[3] Because of the complexity of the γ-ray spectra, and the effects of feeding times (due to the levels shown in Fig. 1 as well as to higher-lying unobserved levels), it was not possible to obtain quantitative lifetimes from observation of the Doppler shifts. However, the limits listed in Table II were obtained from coarse limits on the centroid shifts observed in singles spectra (the 2651-, 1341-, and 551-keV γ rays) or coincidence spectra (the 992-keV γ ray). Table II also lists our best values for the γ-ray and level energies, the latter being corrected for the nuclear recoil effect.

The data of Tables I and II together with the assumptions of selective population and strong alignment of yrast levels in the fusion-evaporation reaction[2,7,9] lead to the spin-parity assignments for the ^{39}Ar excited states shown in Fig. 1. Briefly, the angular distributions expected, assuming strong alignment and pure transitions of the lowest allowed multipolarity, have $-0.2 \gtrsim A_2 \gtrsim -0.3$ for $J_i = J_f + 1$ and $+0.2 \lesssim A_2 \lesssim +0.4$, $-0.05 \gtrsim A_4 \gtrsim -0.15$ for $J_i = J_f + 2$. Regarding the spin-parity assignments, that for the ground state was already known. We have no reliable information on the spin-parity of the 5.536-MeV level from the angular distribution and linear polarization data because of the difficulties mentioned above for the 992-keV γ ray. However, the 992-keV transition is too fast to be quadrupole and so the 5.536-MeV level is most likely $J = \frac{17}{2}$ from the argument for selective population of yrast levels. Because of the nonrigorous basis for these spin-parity assignments they are enclosed in parentheses in Fig. 1.

The γ decay of the 3992-, 4543-, and 5536-keV levels has not been reported previously. A level at an excitation energy of 2650 ± 2 keV, decaying 100% to the ground state, was previously observed via the ^{39}K$(n,p\gamma)^{39}$Ar reaction.[10] A level at an excitation of 5.54 ± 0.01 MeV was recently observed via the ^{37}Cl(α,d) ^{39}Ar reaction[11] in a systematic survey of strong $L = 6$ transitions as a means of

TABLE II. Summary of energy and lifetime measurements for ^{39}Ar.

Initial level (keV)	E_γ (keV)	Mean life (psec)	Assumed multipolarity	$\lvert M(ML)\rvert^2$ (Weisskopf units)
2651.12(25)	2651.02(25)	<4	$E2$	>0.19
3992.05(32)	1340.90(20)	<4	$E1$	$>8.7\times10^{-4}$
4543.13(34)	551.08(10)	$1<\tau<3$	$M1$	$0.06<\lvert M\rvert^2<0.19$
5535.53(45)	992.38(30)	<1	$M1$	>0.032

locating the $[(\text{target})_{J=3/2}\otimes(1f_{7/2})^2{}_{J=7}]_{17/2^+}$ states in ^{35}Cl, ^{37,39}Ar, and ^{41,43}Ca. The combination of this result with ours gives strong support to a $\frac{17}{2}^+$ assignment to the 5.535-MeV level and, by inference, to the other assignments of Fig. 1.

It is of interest to compare the yrast level scheme of Fig. 1 to a weak coupling scheme such as that introduced by Bansal and French.[12] Using the parameters derived by Bernstein[13] from the 2p-1h low-spin states in ^{41}Ca we obtain the predictions shown in Fig. 1. For all three cases, the spectra are built on the ground state of the odd nucleus. The even-nuclei excited states involved are 0^+ and 2^+ for ^{38}Ar, 0^+, 2^+, 4^+, and 6^+ for ^{42}Ca, and 0^+ and 7^+ for ^{42}Sc. A comparison of the experimental results and the weak-coupling predictions suggest that the yrast states of ^{39}Ar observed in this experiment can be very well described by 2p-3h (negative parity) and 3p-4h (positive parity) configurations. The nonobservation of $\frac{9}{2}^+$ and $\frac{11}{2}^+$ yrast levels would suggest that they lie above the $\frac{11}{2}^-$ state.

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