A $J^{\pi} = 6^{-}$ BOUND STATE OF ^{36}Ar

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Two resonances in the ^{35}Cl(p,γ)^{36}Ar reaction with $J^{\pi} = 5^{-}$ and $5^{(-)}$ strongly decay to bound states at $E_x = 6.22$ and 7.35 MeV to which, from γ-ray angular distribution and DSA lifetime measurements, unambiguous assignments of $J^{\pi} = 5^{-}$ and 6^{-} have been made. Shell model calculations show that the four states in question mainly have the $d^3_{3/2}\, f_{7/2}$ configuration, with the three $d_{3/2}$ particles coupled to $J = 5/2$.

In a number of even-A nuclei in the upper half of the sd-shell 4^{-} and 5^{-} states have been found, which should be ascribed to the $(1d_{3/2})^{n}\, 1f_{7/2}$ configuration. For $n = 3$ and 5, however, this configuration should also contain two 6^{-} states and one 7^{-} state which thus far have escaped detection.

This letter reports on part of an investigation of the ^{35}Cl(p,γ)^{36}Ar reaction which had led to the excitation energies, branching ratios, lifetimes and J^{π} values of many resonances and bound states in ^{36}Ar. Protons were accelerated width a 3 MV Van de Graaff generator and γ-ray spectra were taken with 45 and 60 cm^3 Ge(Li) detectors. The target material was $BaCl_2$, enriched to 99.3% in ^{35}Cl, evaportaed onto directly water-cooled tantalum backings.

The decay of the $E_p = 2\,231$ keV ($E_x = 10.67$ MeV) resonance is shown in fig. 1. Angular distribution measurements of all primary and secondary transitions concerned lead to unambiguous assignments (at the 99.9% confidence level) of $J = 5, 6$ and 5 for the $E_x = 6.22$, 7.35 and 10.67 MeV states, respectively. The 6.22 MeV level must have odd parity because its lifetime and branching exclude M2 character for the 6.22 $\rightarrow$ 4.18 MeV transition. An analogous argument, based on the observed large mixing ratio ($\delta = 6.0 \pm 0.9$, sign convention Rose and Brink [3]) for the 7.35 $\rightarrow$ 5.17 MeV transition, leads to odd parity for the 7.35 MeV level.

The present work has shown, from simultaneous (p,γ) and (p,α_0) measurements, that the ^{36}Ar level excited at 2 231 keV in (p,γ) is different from the $J^{\pi} = (3^{-}, 4^{+})$ level exited at 2 230 keV in the ^{35}Cl(p,α_0)^{32}S reaction [4].

Another, weaker, resonance at $E_p = 2\,136$ keV ($E_x = 10.58$ MeV) shows a decay scheme (see fig.1) which is very similar to that of the 2 231 keV resonance, but for an additional 5% branch to the

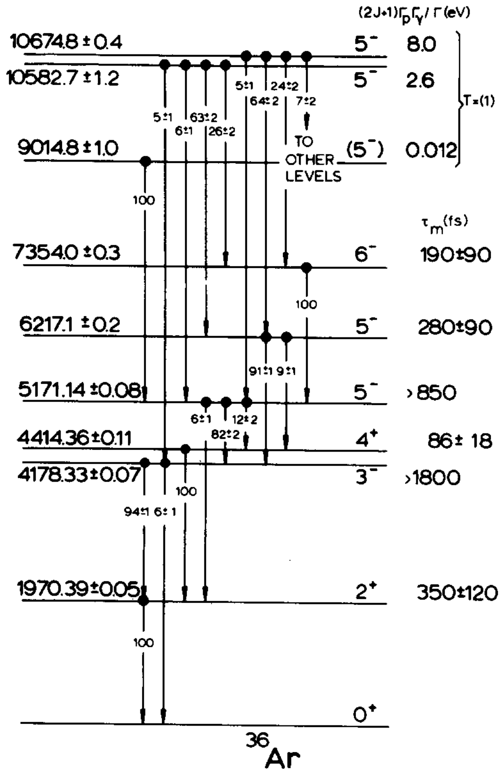

Fig. 1. Gamma-ray decay of 5^{-} and 6^{-} levels excited in the ^{35}Cl(p,γ)^{36}Ar reaction. The J^{π} values of the levels below $E_x = 5.2$ MeV are from ref. [1], the resonance strengths and the decay of the 9.01 MeV resonance from ref. [2]; all other data are from the present work.

3^{-} 4.18 MeV level. Although no angular distribution measurements have been performed at this resonance, the measured transition probabilities for the transitions to 3^{-}, 5^{-} and 6^{-} bound states are sufficiently large to conclude unambiguously to $J^{\pi} = 5^{-}$ for the resonance.

Table 1

Calculated excitation energies and configuration amplitudes of the lowest 5^- and 6^-, T = 0 and 1 states in ^{36}Ar

Experiment			Theory [a]					
E_p (keV)	E_x (MeV)	$J^{\pi}T$	E_x (MeV)	$(1d_{3/2})^3_{JT}\ 1f_{7/2}$				$(1d_{3/2})^3_{JT}\ 2p_{3/2}$
				$JT = \frac{3}{2}\ \frac{1}{2}$	$\frac{5}{2}\ \frac{1}{2}$	$\frac{7}{2}\ \frac{1}{2}$	$\frac{3}{2}\ \frac{3}{2}$	$\frac{7}{2}\ \frac{1}{2}$
2 231	10.67	$5^{(-)}$ (1)	10.30	-0.23	$\underline{+0.55}$	+0.31	-0.72	+0.18
2 136	10.58	5^- (1)	10.00	+0.19	$\underline{-0.57}$	-0.34	-0.70	-0.19
522	9.01	(5^-) (1)	[9.01] [b]	$\underline{0.94}$	-0.27	-0.18	+0.32	+0.08
	7.35	6^- 0	6.44		$\underline{+0.75}$	+0.66		
	6.22	5^- 0	6.53	-0.20	$\underline{-0.95}$	0.00		-0.26
	5.17	5^- 0	[5.17] [b]	$\underline{-0.93}$	+0.13	+0.26		+0.22

a The underlined amplitudes are most important for the discussion in the text.
b Reference energies.

Although the parity of the 10.67 MeV level has remained undetermined, the analogy of its decay with that of the 10.58 MeV level shows that most probably the parity is also odd.

Both these 5^- resonances should have $T = 1$. The 10.67 → 6.22 MeV M1 transition e.g. has a strength of 0.25 W.u. which is appreciably larger than the strength (0.05 W.u.) of the strongest of the 32 known $\Delta T = 0$ M1 transitions between bound states in self-conjugated nuclei in the Z = 3 - 31 region. The resonances should be the analogues of levels in ^{36}Cl at about E_x = 4.0 MeV, a region in which, as yet, very little is known about spins and parities.

There is only one more resonance known [2] which might have $J^{\pi} = 5^-$, $T = 1$, viz. that at E_p = 522 keV (E_x = 9.01 MeV) because it decays 100% to the 5.17 MeV 5^- level (fig. 1).

A simple shell model calculation has been performed to study the odd-parity levels in A = = 36 nuclei. The same shell model space, comprising the $d^n_{3/2}\ f_{7/2}$ and $d^n_{3/2}\ p_{3/2}$ configurations, and the same two-body matrix elements have been used as in ref. [5] which dealt with A = 35, 37 and 39 nuclei. The calculated excitation energies and the amplitudes of the configurations concerned are given in table 1.

Apparently, the lowest 5^- states, both $T = 0$ and $T = 1$, have predominantly $(d^3)_{3/2}$ f character, where $(d^3)_J$ stands for three $1d_{3/2}$ particles coupled to spin J. The next higher 5^-, $T = 0$, the lowest 6^-, $T = 0$ and the two next higher 5^-, $T = 1$ states all have an important $(d^3)_{5/2}$f component.

An investigation [6] of the ^{35}Cl(τ,d)^{36}Ar reaction supports the character of the 5^-, $T = 0$ states given in table 1. The transition to the 5.17 MeV level is very strong (with $l_p = 3$), whereas that to the 6.22 MeV level is unobservably weak.

The strong resonance decay modes are now explained as analogue to anti-analogue M1 transitions between $d^3 f_{7/2}$ configurations, with the M1 operator operating on the $f_{7/2}$ particle. It has been shown e. g. by Maripuu [7] that such transitions for $j = l + \frac{1}{2}$ orbits are much stronger than for $j = l - \frac{1}{2}$. The strengths of the $T = 1 \rightarrow 0$ transitions in question have been calculated with the wave functions given in table 1. The strengths found for the transitions to the 6.22 MeV level are almost correct, whereas the transitions to the 5.17 MeV level are overestimated and those to the 7.35 MeV level are underestimated by the model.

Finally, it might be mentioned that the upper two 5^- resonances act as doorway states. In the ^{35}Cl(p,γ)^{36}Ar reaction they can only be formed via the 4% $(d)^3_{3/2}$f component, whereas the main decay proceeds via the 30% $(d)^3_{5/2}$f component.

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