DISCOVERY OF $\frac{11}{2}^{+}$ LEVEL IN ^{19}F

J. H. AITKEN, K. W. ALLEN *, R. E. AZUMA, A. E. LITHERLAND and D. W. O. ROGERS
University of Toronto, Canada

Received 11 February 1969

A resonance has been discovered in the $^{15}N(\alpha,\gamma)^{19}F$ reaction which strongly populates the recently-discovered [1] $\frac{13}{2}^{+}$ level at 4.648 MeV in ^{19}F. Measurements show that it corresponds to a level with spin $\frac{11}{2}$ in ^{19}F at E_x = 6.500 MeV.

The low-lying even parity levels of ^{19}F are described in the shell model as states of mixed configurations of three nucleons in the s-d shell outside an inert ^{16}O core. The recently-discovered [1] $\frac{13}{2}^{+}$ level in ^{19}F at an excitation energy of 4.648 MeV, the $\frac{9}{2}^{+}$ level (2.78 MeV), the $\frac{3}{2}^{+}$ level (1.56 MeV), the $\frac{5}{2}^{+}$ level (0.197 MeV) and the $\frac{1}{2}^{+}$ level (g.s.), fit fairly consistently into the general framework of this description by the calculation of Elliott and Flowers [2]. However, an $\frac{11}{2}^{+}$ level, required by the model and predicted by the theory to lie above the $\frac{13}{2}^{+}$ level, has not yet been reported.

In an effort to locate the $\frac{11}{2}^{+}$ level, we have extended our study of resonances in the $^{15}N(\alpha,\gamma)^{19}F$ reaction up to E_α = 3.20 MeV [3]. Targets of titanium nitride (99% ^{15}N) on a backing of tantalum were bombarded with currents of He$^+$ of up to 50 μA from the 3 MV Van de Graaff accelerator of the Ontario Cancer Institute. The spectra of the resulting γ-rays were studied with Ge(Li) detectors of 40 cm^3 and 35 cm^3. Fig. 1(a) shows the yield of γ-rays as a function of bombarding energy in the region of interest. The γ-ray spectrum associated with the peak in the yield curve at 3.15 MeV was found to show transitions to the $\frac{13}{2}^{+}$ and $\frac{9}{2}^{+}$ levels in ^{19}F together with decays to the $\frac{1}{2}^{+}$, $\frac{1}{2}^{-}$, $\frac{3}{2}^{-}$, $\frac{5}{2}^{+}$ and $\frac{5}{2}^{-}$ levels. The simplest explanation of this is that two closely-spaced or over-lapping levels of ^{19}F are being formed, one with spin $\geq \frac{9}{2}$, the other of low spin. Dixon and Storey [4] have since shown that at this bombarding energy there are two resonances about 2 keV apart, the higher one decaying to the $\frac{13}{2}^{+}$ and $\frac{9}{2}^{+}$ levels, and the lower one decaying to the low-spin levels. The decay scheme attributed to the high-spin level is shown in fig. 1(b).

The radiative yield $(2J+1)\,\Gamma_\alpha \Gamma_\gamma/\Gamma$ of the high-spin resonance was found to be 5.0 ± 0.5 eV by comparing the γ-ray yield from this resonance with the yield from the E_α = 1.68 MeV resonance in the $^{15}N(\alpha,\gamma)^{19}F$ reaction by use of the same target for both resonances. The yield from the 1.68 MeV resonance in $^{15}N(\alpha,\gamma)^{19}F$ was determined by comparison with the E_α = 1.53 MeV resonance in $^{14}N(\alpha,\gamma)^{18}F$ of which the yield has been measured absolutely by Parker [5]. This latter intercomparison was carried out with a single titanium nitride target containing both ^{14}N and ^{15}N in a known ratio.

Fig. 1(c) shows the angular distribution of the 3.72 MeV γ-ray attributed to the decay of the high-spin resonance level to the $\frac{9}{2}^{+}$ level. Of the postulates $\frac{9}{2}$, $\frac{11}{2}$ and $\frac{13}{2}$ for the spin of the resonance level, only $\frac{11}{2}$ gives a good fit (χ^2 = 4.0). The multipole mixing ratio δ is found to be 0.02 ± 0.02. The best fits for the other postulates have χ^2 = 80 ($\frac{9}{2}$) and χ^2 = 350($\frac{13}{2}$). This angular distribution alone is sufficient to establish the spin of the resonance level as $\frac{11}{2}$.

The 1.852 MeV primary γ-ray from the $\frac{11}{2}$ to $\frac{13}{2}$ transition and the 1.869 MeV secondary γ-ray from the $\frac{13}{2}$ to $\frac{9}{2}$ transition are not completely resolved in the spectra observed at forward angles because the primary γ-ray shows the full Doppler shift. The angular distribution of the two treated as an unresolved doublet is shown in fig. 1(d). The secondary γ-ray is assumed to be pure quadrupole. The multipole mixing ratio of the primary gamma-ray is found to be δ = 0.03 ± 0.03 for the best fit (χ^2 = 1.0). The ratio of the intensities of the primary and secondary γ-rays was measured at 90° and 135° and found to be 1.53 ± 0.06 (theory: 1.490) and 0.80 ± 0.02 (theory: 0.815), respectively. The theoretical ratios are for the spin sequence $\frac{11}{2}$ to $\frac{13}{2}$ to $\frac{9}{2}$ with δ = 0.03.

The identification of the $\frac{11}{2}$ level found in this

* Visiting Scientist, University of Oxford.

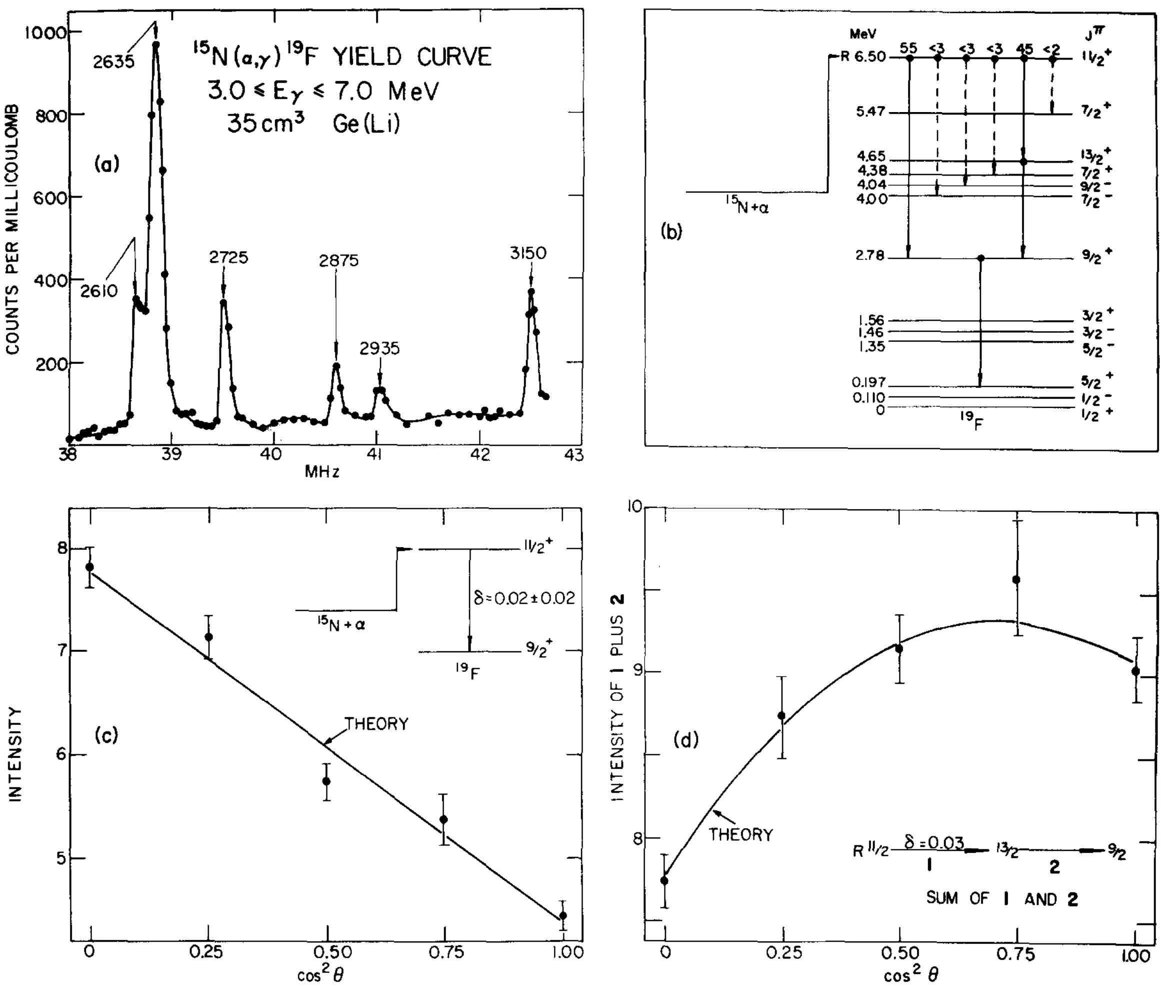

Fig. 1. (a) Gamma-ray excitation curve for the reaction $^{15}N(\alpha,\gamma)^{19}F$ for E_α between 2.5 and 3.2 MeV. (b) Decay and branching ratios of $\frac{11}{2}^+$ level in ^{19}F. (c) Angular distribution of γ-ray attributed to $\frac{11}{2}^+$ to $\frac{9}{2}^+$ transition. (d) Angular distribution of sum of primary and secondary γ-rays attributed to $\frac{11}{2}^+ \to \frac{13}{2}^+ \to \frac{9}{2}^+$ cascade.

work with the $T = \frac{1}{2}$, $J^\pi = \frac{11}{2}^+$ level predicted by Elliott and Flowers [2], Redlich [6], Inoue et al. [7], and most-recently by Benson and Flowers [8], is based on the fact that its energy and modes of decay are in fairly good agreement with theory. Table 1 shows a comparison of experimental and theoretical transition strengths (in single-particle or Weisskopf units [9]). The theoretical values are from the intermediate coupling calculation of Benson and Flowers [8]. The experimental values are calculated from our estimates of the mixing ratios and the yield measurement in which it is assumed that $\Gamma_\alpha \gg \Gamma_\gamma$ for the resonance level. This assumption is reasonable because unless one assumes that $\Gamma_\alpha \gtrsim \Gamma_\gamma$ at least, the measured enhancements of the M1 transitions become improbably large. The assumption that $\Gamma_\alpha \gtrsim \Gamma_\gamma$ leads to $\theta_\alpha^2 \gtrsim 4.4 \times 10^{-3}$

Table 1

Transition	$\lvert M\rvert^2$(Weisskopf units)			
	M1		E2	
	Expt.	Theory	Expt.	Theory
$\frac{11}{2}^+$ to $\frac{9}{2}^+$	0.20 ± 0.03	0.15	$0.06^{+0.18}_{-0.06}$	0.13
$\frac{11}{2}^+$ to $\frac{13}{2}^+$	1.4 ± 0.2	0.84	$3.0^{+9.0}_{-3.0}$	1.97

(for R = 4.864 fm) for the reduced α-particle width. Clearly a measurement of Γ_α for the $\frac{11}{2}^+$ level would be of considerable interest in discussing the validity of the current interpretation of the low-lying positive parity levels of ^{19}F as being due to three nucleons outside an ^{16}O core [2, 6-8].

An $\frac{11}{2}^-$ assignment for the resonance is not ruled out by the present data. However the measured yield would then imply that $\theta_\alpha^2 \gtrsim 6.4 \times 10^{-2}$

This work was supported in part by the National Research Council of Canada.

References

1. K. P. Jackson et al., Bull. Am. Phys. Soc. 13 (1968) 1370.
2. J. P. Elliott and B. H. Flowers, Proc. Roy. Soc. A229 (1955) 536.
3. J. H. Aitken, A. M. Charlesworth, R. E. Azuma and A. E. Litherland, Bull. Am.Phys. Soc. 13 (1968) 651.
4. W. R. Dixon and R. S. Storey, private communication.
5. P. D. Parker, Phys. Rev. 173 (1968) 1021.
6. M. G. Redlich, Phys. Rev. 99 (1955) 1427.
7. T. Inoue, T. Sebe, H. Hagiwara and A. Arima, Nucl. Phys. 59 (1964) 1.
8. H. G. Benson and B. H. Flowers, Nucl. Phys., to be published.
9. D. H. Wilkinson, in Nuclear spectroscopy Part B ed. F. Ajzenberg-Selove. (Academic Press 1960).

* * * * *