Aust. J. Phys., 1976, **29**, 139–48

A Search for an Excited $K^{\pi} = 0^{+}$ Rotational Band in ^{24}Mg

D. Branford,[A,B,C] *L. E. Carlson*,[A,D] *F. C. P. Huang*,[A,E] *N. Gardner*,[B,F] *T. R. Ophel*[A] *and I. F. Wright*[B]

[A] Department of Nuclear Physics, Australian National University, Canberra, A.C.T. 2600.
[B] Department of Physics, Manchester University, England.
[C] Present address: Department of Physics, University of Edinburgh, Scotland.
[D] Present address: Omega Techno Ltd, Edmonton, Alberta, Canada.
[E] Present address: Department of Computer Science, University of Newcastle, N.S.W. 2308.
[F] Present address: BNFL, Seascale, Cumberland, England.

Abstract

A search is described for an excited $K^{\pi} = 0^{+}$ rotational band based on the 6·44 MeV level of ^{24}Mg. Mean nuclear lifetimes have been measured by the Doppler shift attenuation method using the ^{12}C(^{16}O, α)^{24}Mg reaction and the results are $\tau_{m} = 66 \pm 29$, 28 ± 7 and 13 ± 3 fs for levels at 6·44, 8·65 and 10·58 MeV respectively. The absolute transition rates found for the γ decays from the 6·44 and 8·65 MeV levels are in good agreement with the results of shell model calculations if it is assumed that these levels are the 0^{+} and 2^{+} members respectively of the excited $K^{\pi} = 0^{+}$ rotational band. Based on this assumption, a result $Q_{00} = 0 \cdot 48 \pm 0 \cdot 08\,b$ is obtained for the intraband quadrupole moment. From a study of the ^{23}Na(p, γ) reaction, it is established that the $J = 4$ levels at 12·63 and 13·05 MeV do not decay by enhanced E2 transitions to the 8·65 MeV level. This suggests that neither of these levels is the 4^{+} member of the excited $K^{\pi} = 0^{+}$ rotational band. An assignment of $J^{\pi} = 4^{+}$ is made to one member of the doublet at 10·58 MeV.

Introduction

The nucleus ^{24}Mg has many excited states that can be grouped into well-defined rotational bands. The band at lowest excitation is based on the ground state and has $K^{\pi} = 0^{+}$. At higher excitation energies, there are rotational bands with $K^{\pi} = 2^{+}$, 0^{-} and 3^{-} which are built on the excited states at 4·24 MeV ($J^{\pi} = 2^{+}$), 7·55 MeV (1^{-}) and 7·62 MeV (3^{-}) respectively (Branford *et al.* 1971; Endt and Van der Leun 1973). The excitation energies and γ-decay properties of most of the rotational levels are reasonably well described by calculations based on the rotational (collective) model and the shell model. In terms of the collective model, the $K^{\pi} = 2^{+}$ band head is a γ-vibrational state whereas the band heads of the $K^{\pi} = 0^{-}$ and 3^{-} rotational bands arise from octupole vibrations.

All of the models of ^{24}Mg indicate that there exists a $K^{\pi} = 0^{+}$ rotational band built on a low lying excited $J^{\pi} = 0^{+}$ state. This state is most probably the level observed at 6·44 MeV since it is the only excited 0^{+} state below 10 MeV excitation. In terms of the collective model, it is either a β-vibrational state or it arises from a two-phonon γ vibration (Cohen and Cookson 1962). In terms of the shell model, it is a complex many-particle, many-hole state based on the ground state and may possibly have a large $(1d\,2s)^{4}(1f)^{4}$ component in its wavefunction (Strottman and Arima 1971; Strottman 1972, personal communication).

In this paper, we describe a search for the $J^{\pi}, K = 2^{+}, 0$ and $4^{+}, 0$ members of this excited $K^{\pi} = 0^{+}$ rotational band. States with $J^{\pi} = 2^{+}$ occur in ^{24}Mg at $E_{x} = 7 \cdot 35$, 8·65, 9·00 and 9·28 MeV (Endt and Van der Leun 1973). However, only one of these states, the 8·65 MeV level, is known to decay to the 6·44 MeV level (Ollerhead *et al.* 1968; Leccia *et al.* 1973) which suggests that it may be the $2^+,0$ level of interest. To investigate this possibility, the mean nuclear lifetimes of the 8·65 and 6·44 MeV levels were measured by the Doppler shift attenuation method using the heavy-ion induced $^{12}C(^{16}O,\alpha)^{24}Mg$ reaction.

In our search for the $4^+,0$ level of the excited $K^{\pi} = 0^+$ rotational band, we assumed that the 8·65 and 6·44 MeV states are the 2^+ and 0^+ members respectively. Unfortunately, the E versus $J(J+1)$ rule is not well obeyed for ^{24}Mg rotational bands. Consequently, we could not predict accurately the energy of the $4^+,0$ level although it is unlikely to be outside the range $12 < E_x < 14$ MeV. In this region, levels with $J = 4$ have been observed using the $^{23}Na(p,\gamma)$ and $^{20}Ne(\alpha,\gamma)$ resonance reactions at energies $E_x = 12\cdot05$ MeV ($E_p = 374$ keV), 12·50 MeV, 12·63 MeV (987 keV) and 13·05 MeV (1416 keV) (Endt and Van der Leun 1973). To investigate whether or not any of the states at 12·05, 12·63 and 13·05 MeV excited by the $^{23}Na(p,\gamma)$ reaction is the $4^+,0$ level of interest, we made a search for small but significant γ branches to the 8·65 MeV level which would correspond to strong E2 transitions.

Results are also presented for the member of the 10·58 MeV doublet labelled 10·58a by Boydell and Sargood (1975).

Experimental Method

The Doppler shift attenuation measurements were made using $15\,\mu g\,cm^{-2}$ self-supporting and nickel-backed natural carbon targets. These were alternately bombarded for 1 h periods with a $0\cdot1\,\mu A$ beam of $^{16}O^{5+}$ ions from the University of Liverpool tandem accelerator. Beam energies of 28·86 and 34·81 MeV were used. A $15\,\mu m$ nickel foil stopped the beam whilst the α particles from the $^{12}C(^{16}O,\alpha)^{24}Mg$ reaction passed through. These were detected by a radial-position sensitive silicon surface barrier detector which was placed at 0° to the beam direction and subtended a 15° half angle. The α resolution was 600 keV FWHM after corrections had been made for the kinematical peak broadening. Reaction γ rays were detected by a $25\,cm^3$ Ge(Li) detector placed at 0° and subtending a mean half angle of 15°. The γ resolution was 2·3 keV FWHM at 1·33 MeV γ-ray energy. The pulse heights corresponding to α–γ coincidence events were recorded on magnetic tape using an on-line DEC PDP7 computer. At a later date, γ-ray spectra in coincidence with α particles leading to the 6·44, 8·65 and 10·58 MeV levels were obtained.

The $^{23}Na(p,\gamma)$ reaction was studied using a $100\,\mu g\,cm^{-2}$ NaCl target on a water-cooled $25\,\mu m$ tantalum backing. This target was bombarded with a $20\,\mu A$ beam of H^+ ions from the Australian National University 2MV Van de Graaff accelerator. The γ rays emitted following excitation of the 374 and 987 keV resonances were detected using a $35\,cm^3$ Ge(Li) detector at 55° to the beam direction. The front face of the detector was approximately 2 cm from the target, and the γ-ray resolution was 2·5 keV at 1·33 MeV. Spectra were recorded using a 4096-channel pulse height analyser for 24 h in both cases.

A coincidence measurement was made at the 1416 keV resonance using the Ge(Li) detector at 0° to the beam direction and two $12\cdot7\times10\cdot2$ cm NaI(Tl) detectors at 90°. The NaI detector front faces were 12·7 cm from the target. A spectrum of Ge(Li) detector pulses gated by NaI pulses corresponding to $E_\gamma > 3$ MeV (either detector) was recorded over a period of 24 h. The coincidence resolving time was approximately 50 ns which gave a true to random ratio of approximately 50.

Angular distributions of the 8·93 and 2·75 MeV γ rays from the decay of the 1416 keV resonance (see Fig. 2 below) were measured using a $12\cdot7\times10\cdot2$ cm NaI(Tl) detector mounted on a turntable with its front face 21 cm from the target. The reaction rate was monitored by another $12\cdot7\times10\cdot2$ cm NaI detector used at 90°. Small anisotropies in the system were determined using a 1 mm diameter ^{60}Co radioactive source. The γ-ray angular distribution for the weak $R\rightarrow10\cdot58$ MeV transition (see Fig. 2) was determined using the Ge(Li) detector at a distance such that its front face was 7·7 cm from the target.

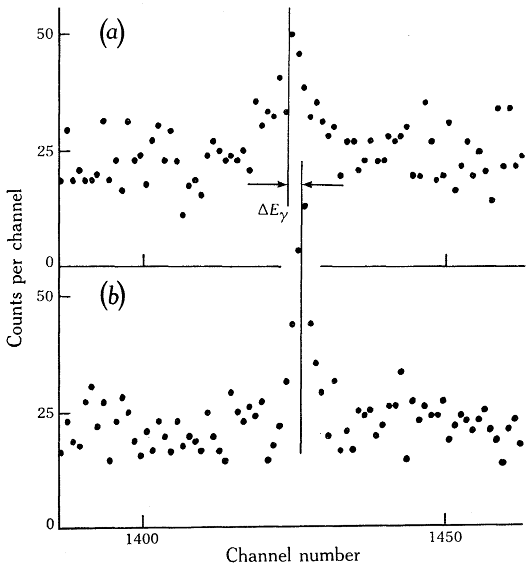

Fig. 1. Portions of γ-ray spectra obtained from the decay of the 8·65 MeV level following the ^{12}C(^{16}O, α)^{24}Mg reaction induced by bombardment of:
(*a*) a nickel-backed target,
(*b*) a self-supporting target.
The change in the centroid ΔE_{γ} of the 7·28 MeV double escape peak caused by the Doppler shift attenuation is indicated.

Results

Lifetime Measurements

An example of the data obtained for the lifetime measurements is shown in Fig. 1. Mean nuclear lifetimes (τ_{m}) were determined in the manner described by Branford and Wright (1973) and Branford *et al.* (1975). The γ rays observed using the self-supporting target were from ^{24}Mg nuclei that decayed whilst recoiling into vacuum, except for a fraction that decayed before leaving the target. The mean energies are given by the well-known Doppler shift formula

$$\bar{E}_{\gamma} = E_0(1+\bar{\beta}\langle\cos\theta\rangle), \qquad (1)$$

where $\bar{\beta}$ is the mean recoil velocity in units of c, $\langle\cos\theta\rangle$ is the mean detection angle and E_0 is the energy that the γ ray would have had if it had been emitted from a nucleus at rest. The γ rays observed using the nickel-backed target were from ^{24}Mg nuclei that decayed after being slowed down to some extent in both the nickel backing and the carbon target material. This gave rise to mean γ energies lower than those obtained using self-supporting targets by amounts ΔE_{γ}. Experimental values for ΔE_{γ} were determined from the differences in peak centroids observed between data obtained with the self-supporting and nickel-backed targets (e.g. see Fig. 1). These results were then compared with the theoretical expressions given by Branford and Wright (1973) and τ_{m} results were obtained.

Lifetime results for the levels considered here are shown in Table 1. An error equal to 15% of τ_m was added in quadrature to the statistical error to account for uncertainties in the stopping power data. Table 1 also shows a comparison of our results with previous measurements. With the possible exception of the result of Alexander *et al.* (1967), which has only a small statistical weight, all the results are in reasonable agreement with each other. The weighted means of the results are used in the following analysis.

Table 1. Mean lifetime results for ^{24}Mg levels

E_x (MeV)	Previous results[A] for τ_m (fs) A	RB	B	MRR	L	Present τ_m (fs)	Weighted mean (fs)
6·44	270±60	240±230	77±23	66±13	110±17	66±29	84±9
8·65	—	—	—	13±5	29±7	28±7	21±4
10·58	—	—	—	—	—	13±3	13±3

[A] References: A, Alexander *et al.* (1967); RB, Robinson and Bent (1968); B, Baker *et al.* (1972); MRR, Meyer *et al.* (1972); L, Leccia *et al.* (1973).

^{23}*Na(p, γ) Measurements*

The angular distributions of γ rays from isolated resonances are generally of the form

$$W(\theta) = 1 + A_2 Q_2 P_2(\cos\theta) + A_4 Q_4 P_4(\cos\theta), \tag{2}$$

where the A's are Legendre coefficients, the Q's are coefficients which take into account the attenuation of the angular distribution due to the finite size of the γ detector and θ is the angle of emission with respect to the beam direction. The measurements made at the 374 and 987 keV resonances were at $\theta = 55°$ where $P_2(\cos\theta) \approx 0$. The term $A_4 Q_4 P_4(\cos 55°)$ is also expected to be small since it is unlikely that the ^{23}Na(p, γ) reaction will strongly align the residual nucleus (incident channel spin = 1 or 2) and Q_4 is approximately 0·2. Therefore, we determined γ branching ratios directly from the intensities of the γ peaks. Upper limits for the $R \to 8\cdot65$ MeV transitions are shown in Table 2.

The 0° coincidence spectrum obtained from the decay of the 1416 keV resonance contained prominent peaks from the 2·75 and 1·37 MeV γ rays but relatively few counts in the region above $E_\gamma = 2\cdot75$ MeV due to the requirement that coincidence NaI pulses have $E_\gamma > 3$ MeV (see Fig. 2). However, in spite of the low number of background counts, there was no evidence of 4·40 and 7·28 MeV γ-ray peaks which would have indicated that the resonance decayed to the 8·65 MeV level. The upper limit for this γ branch is shown in Table 2.

The 4·40 MeV γ-ray result takes into account possible γ–γ angular correlation effects which were calculated using the angular distribution data shown in Fig. 3. Because the entrance channel spin is 2 or 1 the reaction aligns the resonance state such that the spin projections onto the beam direction have $m = 0$, ± 1 and ± 2. In order to determine the parameters $P(0)$, $P(1)$ and $P(2)$ describing the population of these magnetic substates we compared the results shown in Fig. 3 with theoretical distributions given by Rose and Brink (1967). Fig. 4 shows a plot of the χ^2 for a simultaneous fit to both γ rays as a function of the multipole mixing parameter δ(E2/M1) for the 8·93 MeV transition, and the corresponding values of $P(0)$, $P(1)$

Table 2. Branching ratios and γ transition strengths in ^{24}Mg

Transition $E_i(J_i^\pi) \rightarrow E_f(J_f^\pi)$	Branching ratio (%)	References[A]	Transition strengths (W.u.) M1 (10^{-3})	E2
$6\cdot44(0^+) \rightarrow 1\cdot37(2^+)$	84 ± 2	1, 2		$0\cdot58 \pm 0\cdot06$
$6\cdot44(0^+) \rightarrow 4\cdot24(2^+)$	16 ± 2	1, 2		$7\cdot2 \pm 1\cdot1$
$8\cdot65(2^+) \rightarrow 0(0^+)$	<3	2, 3		$<6 \times 10^{-3}$
$8\cdot65(2^+) \rightarrow 1\cdot37(2^+)$	78 ± 3	2, 3	$3\cdot1 \pm 0\cdot6$	$0\cdot36 \pm 0\cdot07$
$8\cdot65(2^+) \rightarrow 4\cdot24(2^+)$	16 ± 3	2, 3	$2\cdot8 \pm 0\cdot8$	$0\cdot90 \pm 0\cdot25$
$8\cdot65(2^+) \rightarrow 6\cdot44(0^+)$	6 ± 1	2, 3		11 ± 3
$10\cdot58(4^+) \rightarrow 1\cdot37(2^+)$	15 ± 5[B]	4		$0\cdot03 \pm 0\cdot01$
$10\cdot58(4^+) \rightarrow 4\cdot12(4^+)$	<27	5	$<2\cdot4$	$<0\cdot36$
$10\cdot58(4^+) \rightarrow 4\cdot24(2^+)$	37 ± 15[C]	5		$0\cdot55 \pm 0\cdot22$
$10\cdot58(4^+) \rightarrow 5\cdot24(3^+)$	48 ± 15[C]	5	$7\cdot7 \pm 2\cdot4$	$1\cdot6 \pm 0\cdot5$
$12\cdot05(4^+) \rightarrow 8\cdot65(2^+)$	$<5\cdot0\,(3\sigma)$	4		$<125\,(3\sigma)$
$12\cdot63(4^+) \rightarrow 8\cdot65(2^+)$	$<1\cdot0\,(3\sigma)$	4		$<0\cdot8\,(3\sigma)$
$13\cdot05(4^+) \rightarrow 8\cdot65(2^+)$	$<0\cdot2\,(3\sigma)$	4		$<2\cdot8\,(3\sigma)$

[A] References: 1, Endt and Van der Leun (1973); 2, Leccia *et al.* (1973); 3, Ollerhead *et al.* (1968); 4, present work; 5, Boydell and Sargood (1975).
[B] Based on relative intensities of γ rays observed at 0°.
[C] Results normalized to include $10\cdot58 \rightarrow 1\cdot37$ MeV transition.

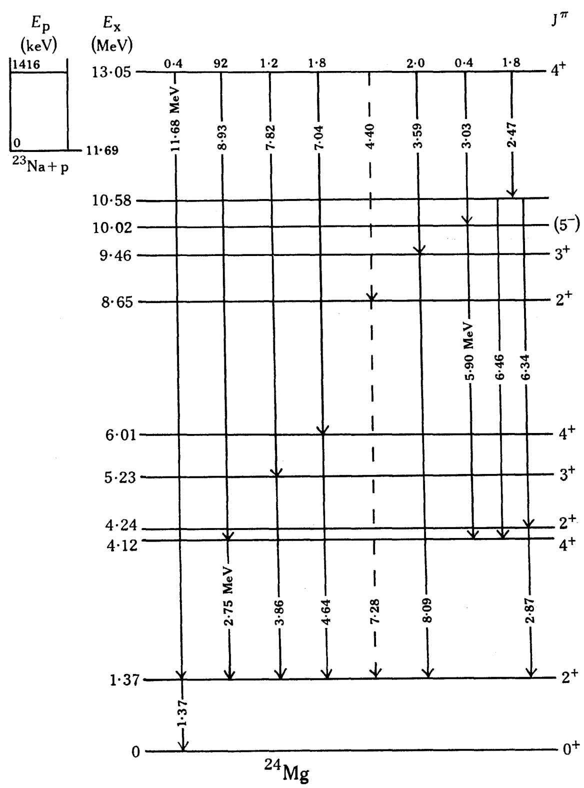

Fig. 2. Gamma ray decay scheme for the 1416 keV ^{23}Na(p, γ) resonance based on the data of Meyer *et al.* (1972) and Leccia *et al.* (1973). The γ intensities are given as percentages. The transitions being sought here are indicated by the dashed lines.

and $P(2)$ which were considered at $0\cdot2$ unit intervals. These data give results of $\delta = 0\cdot00 \pm 0\cdot09$ and $-1\cdot00 \pm 0\cdot18$ for the multipole mixing parameter of the $8\cdot93$ MeV transition, where the errors were calculated using the method of Cline and Lesser (1970). The result $\delta = -1\cdot0$ is unlikely for this transition since it implies an enhanced E2 transition (11 W.u.). We assumed, therefore, that $\delta = 0\cdot00 \pm 0\cdot09$ which gave $P(0) = 0\cdot3 \pm 0\cdot1$, $P(1) = 0\cdot2 \pm 0\cdot2$ and $P(2) = 0\cdot5 \pm 0\cdot1$, where the errors were deduced by considering the range of values each population parameter

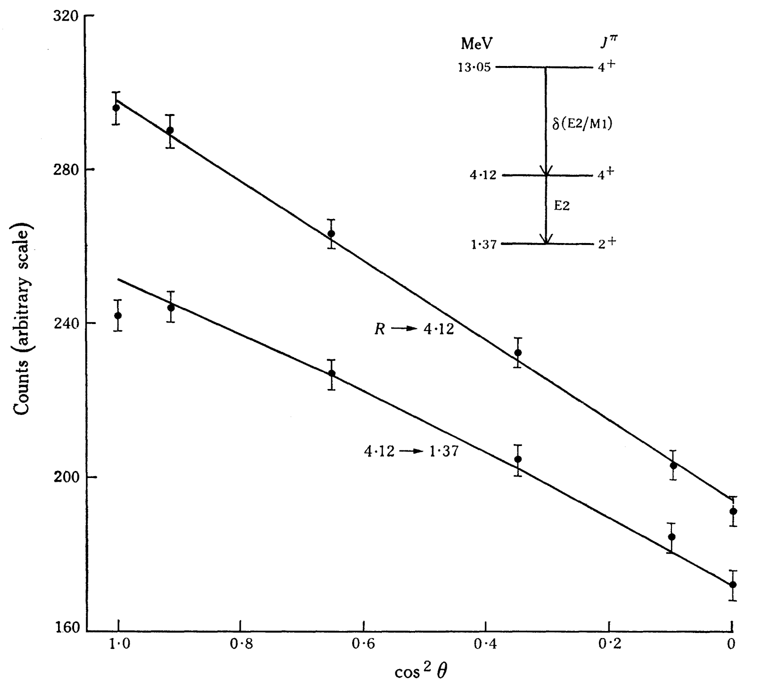

Fig. 3. Angular distribution data obtained following excitation of the 1416 keV ^{23}Na(p, γ) resonance. The theoretical curves were calculated assuming δ(E2/M1) = 0, $P(0) = 0\cdot3$, $P(1) = 0\cdot2$ and $P(2) = 0\cdot5$ (see text).

has in the range $-0\cdot09 < \delta < +0\cdot09$. However, it should be noted that the following analysis is insensitive to this assumption since both values of δ give very similar results for the coefficient $B_2(J_1)$ (Rose and Brink 1967). Using the method described by Watson and Harris (1967), we calculated possible γ–γ angular correlations for a γ cascade through the $8\cdot65$ MeV level. For these calculations, we assumed that the hypothetical $4\cdot40$ MeV transition was E2 whilst all values of δ(E2/M1) were considered for the $7\cdot28$ MeV transition. The results indicated that the effect of γ–γ correlations on our results would be less than 30%, and this has been included in the upper limit shown in Table 2.

Discussion

Table 2 shows absolute transition rates based on the results presented here. The upper limits for the $12\cdot05 \to 8\cdot65$, $12\cdot63 \to 8\cdot65$ and $13\cdot05 \to 8\cdot65$ MeV transition strengths were calculated using known ^{23}Na(p, γ) and ^{20}Ne(α, γ) resonance strengths

(Switkowski *et al.* 1975; Highland and Thwaites 1968; Endt and Van der Leun 1973). The branching ratios used for the 10·58a MeV level are the most recent results of Boydell and Sargood (1975) taken together with the 0° intensity of the 10·58a→1·37 MeV γ ray observed in our $^{12}C(^{16}O,\alpha)^{24}Mg$ data. The conflicting data of Meyer *et al.* (1972) and Leccia *et al.* (1973) have not been included since these authors were not aware that a doublet of states exists at 10·58 MeV. We consider the data of Table 2 as follows.

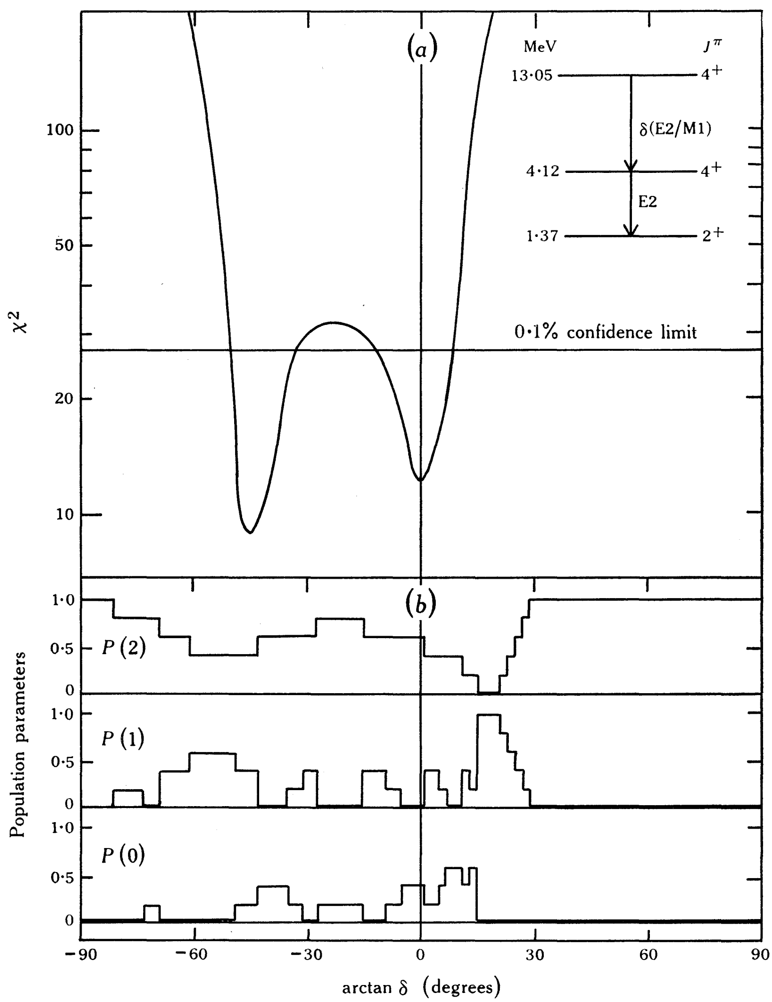

Fig. 4. Plots against arctan δ of: (*a*) the minimum χ^2 obtained from the analysis of the angular distribution data shown in Fig. 3, and (*b*) the population parameters $P(0)$, $P(1)$ and $P(2)$ obtained from the χ^2 analysis.

In Table 3, we compare the measured strengths of γ transitions from the 8·65 and 6·44 MeV levels with the shell-model calculation of Feldmeier *et al.* (1973). We identify the 2_3 level of the calculation at 7·7 MeV with the 8·65 MeV level. A comparison is not made with the results of Strottman and Arima (1971) which are known to contain errors (Branford *et al.* 1975). The E2 strengths for the 8·65→1·37 and

$8 \cdot 65 \rightarrow 4 \cdot 24$ MeV transitions are given as upper limits since the multipole mixing parameters δ(E2/M1) have not been measured. It should be noted, however, that if the $8 \cdot 65$ MeV level has $K = 0$ then M1 transitions to $K = 0$ and 2 rotational levels are forbidden by K-selection rules. Assuming this to be the case, there is reasonable agreement between the experimental transition strengths and theory. We conclude therefore that the data presented here weakly support the assumption that the $6 \cdot 44$ and $8 \cdot 65$ MeV levels are the 0^+ and 2^+ members of an excited $K = 0$ rotational band.

Table 3. Comparison of experimental E2 γ transition strengths with theory

Transition $E_i(J_i^\pi) \rightarrow E_f(J_f^\pi)$	E2 transition strength (W.u.) Shell model result[A]	Present experiment
$6 \cdot 44(0^+) \rightarrow 1 \cdot 37(2^+)$	$0 \cdot 88$	$0 \cdot 58 \pm 0 \cdot 06$
$6 \cdot 44(0^+) \rightarrow 4 \cdot 24(2^+)$	$5 \cdot 07$	$7 \cdot 2 \pm 1 \cdot 1$
$8 \cdot 65(2^+) \rightarrow 0(0^+)$	$0 \cdot 037$	$< 6 \times 10^{-3}$
$8 \cdot 65(2^+) \rightarrow 1 \cdot 37(2^+)$	$0 \cdot 10$	$\leqslant 0 \cdot 36 \pm 0 \cdot 07$
$8 \cdot 65(2^+) \rightarrow 4 \cdot 24(2^+)$	$0 \cdot 039$	$\leqslant 0 \cdot 90 \pm 0 \cdot 25$
$8 \cdot 65(2^+) \rightarrow 6 \cdot 44(0^+)$	$13 \cdot 2$	11 ± 3

[A] Feldmeier *et al.* (1973).

The symmetric rotator model predicts that the reduced E2 transition between the 2^+ and 0^+ members of a $K = 0$ rotational band is given by

$$B(\mathrm{E2}) = (5/16\pi)e^2 Q_{00}^2 \,|\, (2,2,0,0 \,|\, 0,0) \,|^2. \tag{3}$$

Using this expression we determined that the $8 \cdot 65 \rightarrow 6 \cdot 44$ MeV transition corresponds to a quadrupole moment of $Q_{00} = 0 \cdot 48 \pm 0 \cdot 08\, b$. This is smaller than the quadrupole moment for the ground state rotational band ($Q_{00} = 0 \cdot 64 \pm 0 \cdot 02\, b$), which may suggest that the $6 \cdot 44$ MeV level is not as distorted as the ground state. Another interesting result is that the quadrupole moment deduced from the $6 \cdot 44 \rightarrow 4 \cdot 24$ MeV transition is $Q_{20} \approx 0 \cdot 20\, b$, which is comparable with that obtained by Branford *et al.* (1975) from the $K^\pi = 2^+$ to 0^+ ground state interband transitions ($Q_{20} = 0 \cdot 17 \pm 0 \cdot 01\, b$).

Table 2 shows that the upper limits of the γ strengths for the E2 transitions from the $12 \cdot 63$ and $13 \cdot 05$ MeV levels to the $8 \cdot 65$ MeV levels are less than 3 W.u. (3σ). This strongly suggests that neither of these levels is the 4^+ member of an excited $K^\pi = 0^+$ rotational band which includes the $6 \cdot 44$ and $8 \cdot 65$ MeV levels. The result for the $12 \cdot 05$ MeV level is inconclusive. Unfortunately, the small (p, γ) resonance strength of $0 \cdot 013$ eV precluded a coincidence measurement. In view of the above considerations and those presented in the Introduction, it is clear that further experiments should be carried out to search for the $4^+, 0$ level.

We now consider the $10 \cdot 58$ MeV level. Boydell and Sargood (1975) point out that two levels, which they label $10 \cdot 58$a and $10 \cdot 58$b MeV, occur at this energy and that $10 \cdot 58$a MeV is populated by γ decay from the 1416 keV resonance. The lifetime result reported here refers to the $10 \cdot 58$a MeV level. The level has parity $(-1)^J$ because it is strongly populated by the ^{12}C(^{16}O, α)^{24}Mg reaction at angles near to 0° (Litherland 1961). The results presented in Table 2 taken together with the strength of the transition from the 1416 keV 4^+ resonance restrict the possible J^π assignments to 3^- or 4^+, since any other assignments would imply unreasonably large E2, E3 etc. transition strengths. The results obtained for the γ angular distribution from the $R \to 10 \cdot 58$a MeV transition are shown in Fig. 5. These results were compared with

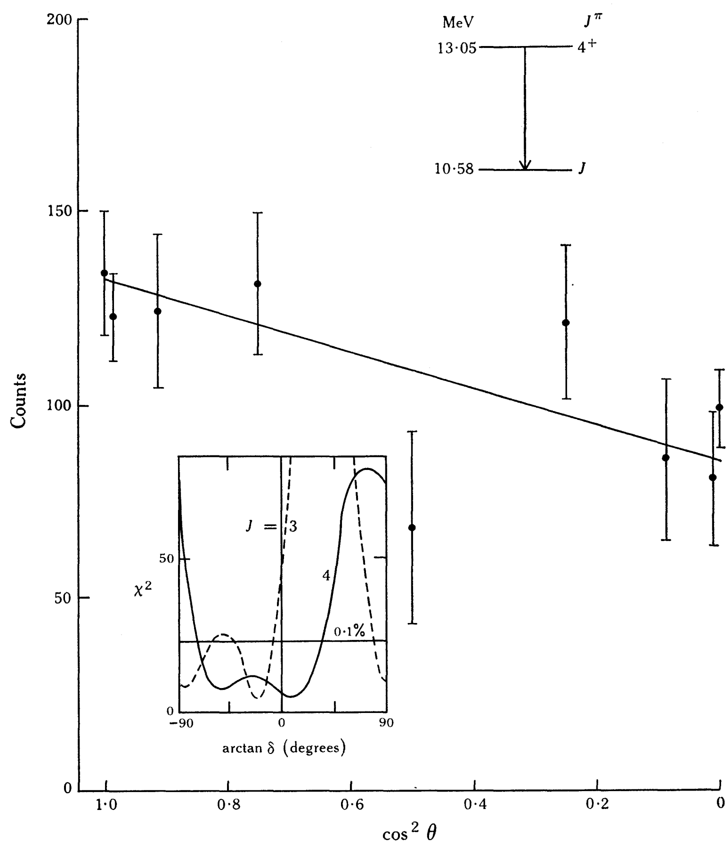

Fig. 5. Angular distribution data obtained for the γ transition from the 1416 keV ^{23}Na(p, γ) resonance to the $10 \cdot 58$ MeV level. The inset shows the minimum χ^2 versus arctan δ for the analyses made assuming $J = 3$ and 4. The $0 \cdot 1\%$ confidence level is indicated.

theoretical angular distributions which were normalized to the data so as to minimize χ^2. A plot of the minimum χ^2 versus δ is also shown in Fig. 5. These data indicate that if $J^\pi = 3^-$ is assumed then χ^2 exceeds the $0 \cdot 1\%$ confidence limit unless δ(M2/E1) $> 0 \cdot 1$, which would imply that the M2 component of the $R \to 10 \cdot 58$ MeV transition exceeds 500 W.u. Since such a transition is extremely unlikely, we conclude that the $10 \cdot 58$ MeV level has $J^\pi = 4^+$.

References

Alexander, T. K., *et al.* (1967). Proc. Gatlinburg Conf. on Nuclear Physics (Ed. J. A. Becker), p. 367 (Academic: New York).
Baker, S. I., *et al.* (1972). *Nucl. Phys.* A **196**, 197.
Boydell, S. G., and Sargood, D. G. (1975). *Aust. J. Phys.* **28**, 369.

Branford, D., Gardner, N., and Wright, I. F. (1971). *Phys. Lett.* B **36**, 456.
Branford, D., McGough, A. C., and Wright, I. F. (1975). *Nucl. Phys.* A **241**, 349.
Branford, D., and Wright, I. F. (1973). *Nucl. Instrum.* **106**, 437.
Cline, D., and Lesser, P. M. S. (1970). *Nucl. Instrum.* **82**, 291.
Cohen, A. V., and Cookson, J. A. (1962). *Nucl. Phys.* **29**, 604.
Endt, P. M., and Van der Leun, C. (1973). *Nucl. Phys.* A **214**, 1.
Feldmeier, H., Manakos, P., and Wolff, T. (1973). *Z. Phys.* **258**, 81.
Highland, G. J., and Thwaites, T. T. (1968). *Nucl. Phys.* A **109**, 163.
Leccia, F., Aléonard, M. M., Castéra, D., Hubert, Ph., and Menrath, P. (1973). *J. Phys.* (*Paris*) **34**, 147.
Litherland, A. E. (1961). *Can. J. Phys.* **46**, 1381.
Meyer, M. A., Reinecke, J. P. L., and Reitman, D. (1972). *Nucl. Phys.* A **185**, 625.
Ollerhead, R. W., Kuehner, J. A., Levesque, R. J. A. and Blackmore, E. W. (1968). *Can. J. Phys.* **46**, 1381.
Robinson, S. W., and Bent, R. D. (1968). *Phys. Rev.* **168**, 1266.
Rose, H. J., and Brink, D. M. (1967). *Rev. Mod. Phys.* **39**, 306.
Strottman, D. (1972). *Phys. Lett.* B **39**, 457.
Strottman D., and Arima, A. (1971). *Nucl. Phys.* A **162**, 605.
Switkowski, Z. E., O'Brien, R., Smith, A. K., and Sargood, D. G. (1975). *Aust. J. Phys.* **28**, 141.
Watson, D. D., and Harris, G. I. (1967). *Nucl. Data* A **3**, 25.

Manuscript received 20 October 1975