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Rotational properties of the ^{25}Mg doublet at 2·7 MeV

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Abstract. The reaction ^{27}Al (d, α)^{25}Mg was used to study the decay of the ^{25}Mg levels at 2·738 and 2·801 MeV. A simple rotational model calculation without band mixing did not account for the measured branching ratios. The discussion of the existing experimental data suggests that band mixing plays an important role in this case.

1. Introduction

The collective model has been used with some success to explain the properties of low lying energy levels in the mirror nuclei ^{25}Mg and ^{25}Al.

Rotational bands based on Nilsson states 5, 9, 11 and 14 with $K^{\pi} = 5/2^{+}$, $1/2^{+}$, $1/2^{+}$, and $1/2^{-}$ respectively, have been considered (Litherland *et al.* 1958, Sharpey-Schafer *et al.* 1968, Sowerby and McCallum 1968, Sheline and Harlan 1962, Bhatt 1962) to interpret the energies and decay schemes of energy levels below 4·5 MeV in both nuclei.

A substantial amount of evidence (Sharpey-Schafer *et al.* 1968, McCallum and Sowerby 1967, Anyas-Weiss and Litherland 1969) has indicated that the levels at 0·585, 0·975, 1·960 and 2·738 MeV in ^{25}Mg and the mirror levels in ^{25}Al, are members of the lowest rotational band with $K^{\pi} = 1/2^{+}$. There is fairly good agreement in ^{25}Mg between the experimental E2 strengths for transitions within the $K^{\pi} = 1/2^{+}$ band and the collective model E2 strengths (Sharpey-Schafer *et al.* 1968). However ^{25}Al does not exhibit such a good agreement (Anyas-Weiss and Litherland 1969). Studies of proton scattering (Ottaviani and Zuffi 1970) and inelastic scattering of alpha particles (Blair and Naqib 1970) in ^{25}Mg seem to suggest band mixing between the $K^{\pi} = 5/2^{+}$ ground state band and the lowest $K^{\pi} = 1/2^{+}$ band. This mixing implies that the nucleus has an asymmetric deformation. Chi and Anderson (1969) made use of a nonaxial model to calculate the electromagnetic transitions, but the quantitative agreement between model and experiment is not satisfactory.

The level at 2·801 MeV in ^{25}Mg is supposed to be the second member of the $K^{\pi} = 1/2^{+}$ band based on the 2·562 MeV level (Sharpey-Schafer *et al.* 1968) and the same is assumed for the corresponding levels in ^{25}Al (Litherland *et al.* 1958).

We have studied the decay of the 2·738 MeV and the 2·801 MeV levels in ^{25}Mg using the reaction ^{27}Al (d, α)^{25}Mg and the collective model to discuss the measured branching ratios.

2. Experimental method and results

A deuteron beam from the LFEN 2 MeV Van de Graaff was used to bombard a selfsupporting ^{27}Al target of approximate thickness 20 μg cm^{-2}. The α particles from the reaction ^{27}Al (d, α)^{25}Mg were detected using an annular surface barrier detector at an angle of 180° to the beam direction. The detector was polarized in such a way that the depleted layer was just enough to stop the highest energy alpha particles in the spectrum; this kept the proton events from competing reactions at amplitudes well below the region of interest. A particle resolution of 60 keV was obtained using integration and differentiation time constants of 0·5 μs.

The γ rays were detected with a 3×3 in^2 NaI(Tl) detector placed at 14 cm from the target and spectra were taken at five angles relative to the beam direction (25°, 40°, 55°, 70°, 90°). The γ ray spectra were taken in coincidence with the α particle events in the region corresponding to the ^{25}Mg 2·738 and 2·801 MeV excited states. Since the particle resolution was not sufficient to separate the two levels, the coincidence γ ray spectra were taken at two different deuteron bombarding energies, 1·8 and 1·9 MeV. The ^{25}Mg state at 2·738 MeV is excited by this reaction more readily than its 2·801 MeV companion in the range of bombarding energies below 2·2 MeV. However, it was found that at 1·9 MeV both levels were about equally excited and with reasonable yield. Since at 1·8 MeV the 2·738 MeV state is dominant, the coincidence γ ray spectra at the two bombarding energies are markedly different and allow a conclusive assignment of the γ ray branches. The integrated γ ray spectra are shown in figure 1.

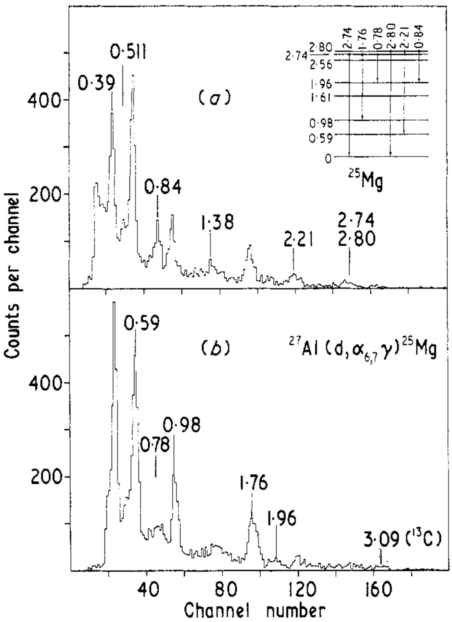

Figure 1. Angle integrated gamma ray spectra obtained at the two bombarding energies (*a*) 1·9 MeV and (*b*) 1·8 MeV. Numbers above the peaks and in the level diagram are energies in MeV.

The particle–gamma coincidences were used to gate a 400 channel analyser in which the γ ray events were accumulated. Typical runs were made for about 800 μC at an average current of 0·1 μA and at least five runs were made for each angle.

The spectra obtained at each angle were added up and the sums were normalized for the same particle intensity and analysed in terms of lineshapes, of the appropriate gamma ray energies (Heath 1964). The spectra thus obtained were corrected for photopeak efficiency, for a slight anisotropy in the target chamber and for random coincidences. The relative intensities were obtained from the value of the A_0 coefficients of Legendre polynomial fits to the observed intensities and are shown in table 1 normalized to a total 100 decays of each level.

Table 1. Summary of results for ^{25}Mg

	Initial state (MeV)	Final state (MeV)	Ground state ($K^\pi = 5/2^+$)	0·585 ($K^\pi = 1/2^+$)	0·975 ($K^\pi = 1/2^+$)	1·614 ($K^\pi = 5/2^+$)	1·960 ($K^\pi = 1/2^+$)
Sharpey-Schafer *et al.* (1968) $^{25}Mg(pp')^{25}Mg$	2·738		7 ±2		86 ±2		7 ±4
	2·801		25 ±5	40 ±5			35 ±5
Sowerby and McCallum (1968) $^{25}Mg(pp')^{25}Mg$	2·738		7 ±2		85 ±3	< 2	8 ±3
	2·801		23 ±5	40 ±5	< 3	< 6	37 ±7
Sowerby *et al.* (1969) $^{24}Mg(d, p\gamma)^{25}Mg$	2·738		7 ±2		87 ±3	< 2	6 ±2
	2·801		24 ±2	37 ±3	< 5	< 2	39 ±3
Present work — experiment	2·738		7 ±6		83 ±5		10 ±2
	2·801		22 ±6	41 ±6			37 ±4
Present work — rotational model predictions		Q (mb)					
	2·738	615	0·5		63·3		36·2
		990	0·1		76·4		23·5
	2·801	615	9·3	11·5			79·2

The measured branching ratios agree quite well with earlier results obtained using different reactions (table 1).

3. Discussion

The equilibrium distortion of ^{25}Mg and ^{25}Al is supposed to lie between $\eta = 4$ and $\eta = 6$ as inferred by Litherland *et al.* (1958) from a comparison between the results of experiment and the predictions of the collective model. The ground state quadrupole moment of ^{25}Mg has been measured by Lurio (1962) to be $Q = 220$ mb which leads to a value of 616 mb for the intrinsic quadrupole moment Q_0 of the ground state band. This result compares well with the value $Q_0 = 550 \pm 130$ mb obtained by Sharpey-Schafer *et al.* (1968) from the E2 transition strength between the level at 1·614 MeV and the ground state. The intrinsic quadrupole moment of the lowest $K^\pi = 1/2^+$ rotational band in ^{25}Mg was calculated by these authors, from the E2 transition strength between the levels at 1·960 and 0·585 MeV, to be $Q_0 = 990$ mb. For the mirror nucleus ^{25}Al the intrinsic quadrupole moments of the ground state and of the lowest $K^\pi = 1/2^+$ bands are quoted to be 450 ± 40 mb and 690 ± 70 mb respectively by Anyas-Weiss and Litherland (1969).

The rotational model, without band mixing, was used to predict the branching ratios of the two levels of ^{25}Mg at 2·738 and 2·801 MeV; the calculated values are shown in table 1 together with the experimental results. In these calculations the gyromagnetic ratio g_R of the core was taken equal to Z/A and the values of g_l and g_s are those of the free neutron. The parameter κ was fixed equal to 0·1.

In this way, it was found that for the decay of the 2·738 MeV level the ratio of the branches within the band $K^\pi = 1/2^+$ is about 3 for $Q_0 = 990$ mb and 2 for $Q_0 = 616$ mb while the experimental ratio value is about 8. To obtain closer agreement a much greater deformation ($\eta > 6$, ie $Q_0 > 990$ mb) would be needed. This was thought to be unreasonable and it would be incompatible with the measured 35 Wu transition strength between the $5/2^+$ and $1/2^+$ members of the $K^\pi = 1/2^+$ band on the assumption of a simple rotational model (Sharpey-Schafer *et al.* 1968). Also the values of $\kappa = 0·07$ and $g_R = 0·3$, often used in this region of the periodic table (Bhatt 1962, Mottelson and Nilsson 1959) provide an even larger disagreement.

A similar discrepancy is also exhibited by the mirror state at 2·723 MeV in ^{25}Al. Litherland *et al.* (1958) calculated the transition probabilities for the decay of this state and found for the two transitions within the band $K^\pi = 1/2^+$ a ratio smaller by a factor of 10 than the experimental value.

Sowerby and McCallum (1968) report a quantitative agreement between the measured branching ratios of the 2·738 MeV level in ^{25}Mg and the collective model prediction but it must be noted that their estimate for the mixing ratio of the transition to the level at 1·960 MeV, which they use to calculate the branching ratios, is well outside the measured value (Sowerby *et al.* 1969).

Since in ^{25}Mg the E2 strengths are reasonably accounted for (Sharpey-Schafer *et al.* 1968), while the branching ratios are not, it seems that the MI in-band transition strengths are overestimated by the collective model without band mixing. This conclusion seems to be compatible with the larger discrepancies that are observed in the mirror nucleus ^{25}Al. The enhanced out-of-band transition from the $5/2^+$ 1·790 MeV level in ^{25}Al to the ground state, seems to suggest some degree of mixing between the $K^\pi = 5/2^+$ and $1/2^+$ lowest bands (Anyas-Weiss and Litherland 1969). The situation is apparently similar in the ^{25}Mg nucleus (Sharpey-Schafer t *al.* 1968).

The decay of the 2·801 MeV level in ^{25}Mg is observed to consist only of out-of-band transitions. Therefore a better agreement between model and experiment than that observed for the 2·738 MeV level is not expected. The model predictions for the observed transitions, assuming that this level is the second member of the $K^{\pi} = 1/2^{+}$ band based on the 2·562 MeV state, are also clearly in disagreement with the experimental data; it must be noted that, since there is no information concerning the quadrupole moment of this band, a ground state quadrupole moment of 615 mb was assumed in the calculations. Mixing of the $K^{\pi} = 1/2^{+}$ bands based on orbits 9 and 11 in mass 25 is also implied by the recent studies of the β decay of ^{25}Na by Jones *et al.* (1970).

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