High spin negative parity states in ^{29}Si associated with oblate deformation (population using ^{26}Mg(α,n) reaction)

1973 J. Phys. A: Math. Nucl. Gen. 6 L67

(http://iopscience.iop.org/0301-0015/6/6/001)

J. Phys. A: Math., Nucl. Gen., Vol. 6, June 1973. Printed in Great Britain. © 1973

LETTER TO THE EDITOR

High spin negative parity states in ^{29}Si associated with oblate deformation

D A Viggars, P A Butler, P E Carr†, L L Gadeken, A N James, P J Nolan and J F Sharpey-Schafer
Oliver Lodge Laboratory, University of Liverpool, Liverpool, L69 3BX, UK

Received 5 April 1973

Abstract. Spin and parity assignments of $11/2^-$ and $13/2^-$ have been made for levels at 6·781 MeV and 8·761 MeV respectively in ^{29}Si using angular correlation, γ ray linear polarization and lifetime measurements. The properties of the levels are consistent with their being high spin members of a $K^\pi = 7/2^-$ rotational band based on the Nilsson orbit [303] with oblate deformation.

The lowest energy negative parity state in ^{29}Si has $J^\pi = 7/2^-$ which, as Bromley *et al* (1957) pointed out, suggests oblate deformation in a Nilsson model description. Bardin *et al* (1970) showed that the $7/2^-$ (3·624 MeV) and $9/2^-$ (5·255 MeV) levels in ^{29}Si could be part of a rotational band and showed that the mixing ratio of the γ decay between the levels was negative. They noted that in the Nilsson model this was consistent with an oblate deformation. Bailey *et al* (1972) proposed the level at 6·781 MeV as a possible $11/2^-$ member of the band. Recently Ragnarsson and Nilsson (1970), using the core renormalization procedure of Strutinsky (1967) to elaborate the model, have predicted properties of the oblate $K^\pi = 7/2^-$ rotational band in ^{29}Si.

Further evidence is needed to establish firmly the existence of an oblate $K^\pi = 7/2^-$ rotational band in ^{29}Si since an alternative explanation of the $7/2^-$ and $9/2^-$ levels together with other negative parity levels might be provided by the weak coupling of an $f_{7/2}$ particle to a ^{28}Si core.

We have shown that the states at 6·781 MeV and 8·761 MeV have spins and parities $11/2^-$ and $13/2^-$. Using only general rotational model considerations we have shown that they are part of a good oblate $K^\pi = 7/2^-$ rotational band.

We used the reaction ^{26}Mg(α,n) ^{29}Si, on a target consisting of 1mg cm^{-2} of ^{26}Mg (enriched to 99·5%) on a thick gold backing, to populate states in ^{29}Si and to carry out Doppler shift attenuation and angular correlation measurements. An escape-suppressed spectrometer (Sharpey-Schafer *et al* 1971) was used to detect the γ rays.

It is expected that in an (α,n) reaction, where most γ rays are strongly Doppler broadened, γ rays from states populated just above threshold will appear as sharp peaks in the spectrum. We took γ ray spectra at α particle energies of 10·0 MeV and 10·5 MeV. At 10·5 MeV sharp γ rays were observed at $3505·6 \pm 0·8$ keV and $1979·2 \pm 0·5$ keV which were not present at 10 MeV. These correspond well to transitions from a state at $8760·6 \pm 0·7$ keV to the states (Bailey *et al* 1972) at $5255·1 \pm 0·5$ keV and $6781·4 \pm 0·7$ keV. This is in good agreement with the energy of 8760 ± 5 keV quoted by Endt and van der Leun (1967) for level 62 in their compilation.

---

† Now at Ferranti Ltd, Western Road, Bracknall, Berkshire, RG12 1RA, UK.

The Doppler shift attenuation method was used to determine the lifetime of the 8·761 MeV state from the centroids of the 3·506 MeV and 1·979 MeV γ ray peaks measured at 10·5 MeV bombarding energy at five angles between 0° and 90°. The lifetime of the level was inferred to be less than 15 fs using a program based on Blaugrund's (1966) application of the stopping power theory of Lindhard *et al* (1963).

Angular distributions of the decays of the 6·781 MeV and 8·761 MeV levels were measured at five angles between 0° and 90° using bombarding energies of 8·5 MeV and 10·5 MeV respectively. The data were analysed by the usual least-squares fitting techniques, relative populations of the magnetic substates having been calculated using the statistical model program 'MANDY' (Sheldon and van Patter 1966). It was found that changes of the order of 10% in the relative substate populations had little effect on

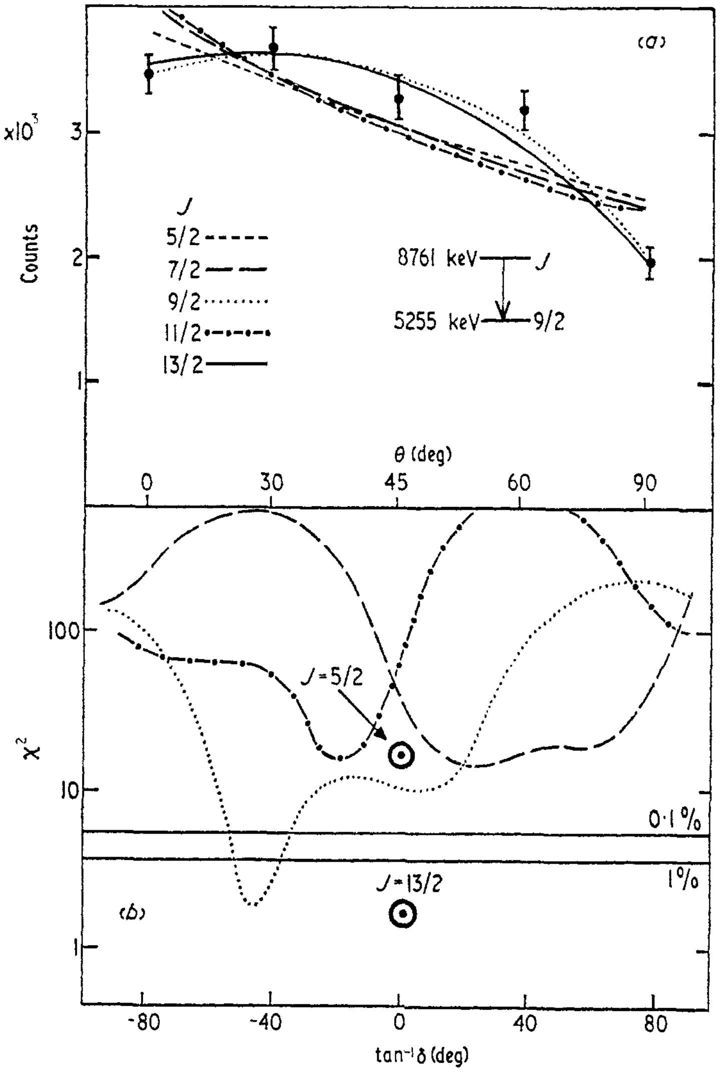

Figure 1. (*a*) The angular distribution of the 3·506 MeV γ ray together with the best theoretical fits for various spin hypotheses. The experimental Legendre polynomial coefficients for the distribution are $A_2 = 0{\cdot}43 \pm 0{\cdot}04$, $A_4 = -0{\cdot}25 \pm 0{\cdot}05$. (*b*) A plot of χ^2 against $\tan^{-1}\delta$ for the 3·506 MeV γ ray for various spin hypotheses.

the quality of the fits. The sign convention of Rose and Brink (1967) was used and errors on the mixing ratios were calculated using the method of Cline and Lesser (1970).

The analysis of γ rays from the decays of the 6·781 MeV level was unreliable because the γ rays of interest were contaminated by single- and double-escape peaks. Since the level decays with a lifetime (Bailey *et al* 1972) of less than 10 fs to levels with spins 7/2 and 9/2 its spin must be 5/2, 7/2, 9/2 or 11/2. Any other spin would imply unreasonably large transition strengths of multipole order 3 or higher. None of the four possibilities were excluded by the angular distribution data, but 5/2 may be eliminated because the 5/2 to 9/2 transition would have an E2 strength of 1000 Wu (Weisskopf units) or more, or an even larger M2 strength. Similar arguments show that the level must have negative parity.

For the 8·761 MeV level the decay to the 5·255 MeV level gave two spin possibilities: $J = 9/2$ with $\delta = -1{\cdot}0 \pm 0{\cdot}2$ and $J = 13/2$ with $\delta = 0$ (figure 1). If the parity of the 8·761 MeV level is positive then, using the measured lifetime, the 9/2 and 13/2 spin hypotheses imply M2 strengths for the transition to the 5·255 MeV state of greater than 130 Wu and greater than 330 Wu respectively. The level must therefore be $(9/2, 13/2)^-$.

In order to resolve the ambiguities in the spin assignments of the 6·781 MeV and 8·761 MeV levels an experiment was carried out to measure the linear polarization of the γ rays originating from these levels. This was done using a Compton polarimeter fully described by Butler *et al* (1973) consisting of three Ge(Li) detectors, one acting as a scatterer of the γ rays and two as absorbers, one in the reaction plane and one normal to it. Linear polarizations were measured at a polar angle of 90° using the reaction ^{26}Mg(α,n) ^{29}Si at a bombarding energy of 11 MeV.

The measured polarizations of the 3·506 MeV and 3·157 MeV γ rays are shown and compared with the values expected on the basis of the mixing ratios implied by the various spin hypotheses in table 1. It is clear that $13/2^-$ is strongly favoured for the 8·761 MeV state. For the 6·781 MeV state the polarization results select $11/2^-$. Accordingly we assign spins $11/2^-$ and $13/2^-$ to the 6·781 MeV and 8·761 MeV levels respectively.

Table 1. Comparison of experimentally observed polarizations (P_{obs}) with polarization calculated from the observed angular distributions (P_{calc}) for each spin hypothesis

6·781 MeV→3·624 MeV			8·761 MeV→5·255 MeV		
J_i^π	P_{calc}	P_{obs}	J_i^π	P_{calc}	P_{obs}
$11/2^-$	$+0{\cdot}70 \pm 0{\cdot}01$	$+0{\cdot}70 \pm 0{\cdot}19$	$13/2^-$	$+0{\cdot}70 \pm 0{\cdot}02$	$+0{\cdot}67 \pm 0{\cdot}39$
$9/2^-$	$-0{\cdot}55 \pm 0{\cdot}10$		$9/2^-$	$-0{\cdot}03 \pm 0{\cdot}10$	
$7/2^-$	$-0{\cdot}32 \pm 0{\cdot}05$				

There are two possibilities for the mixing ratio of the 1·979 MeV ($13/2^-$ to $11/2^-$) γ ray, $-3{\cdot}7 \pm 1{\cdot}7$ and $-(0{\cdot}5^{+0{\cdot}5}_{-0{\cdot}2})$. The former leads to an E2 strength of 170 Wu or more and is thus improbable. We have adopted the latter value.

A plot of the proposed $K^{\pi} = 7/2^-$ band level energies against $J(J+1)$ is shown in figure 2. The γ ray decays of the levels, which are all in-band, and the measured branching ratios of the decays are shown in figure 3. The theoretical E2 transition strengths and multipole mixing ratios shown in table 2 have been calculated using the simple rotational model on the basis of the values for the 5·255 MeV to 3·624 MeV transition. It will be noted that agreement is good between prediction and experiment

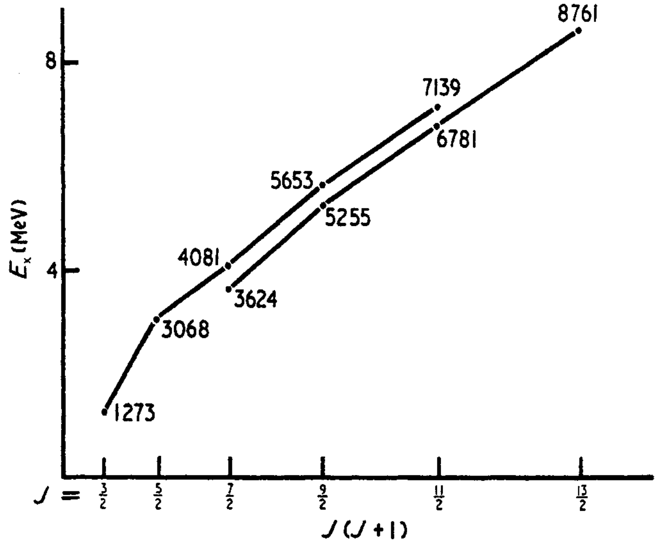

Figure 2. A plot of energy against $J(J+1)$ for the members of the $K^{\pi} = 3/2^+$ and $K^{\pi} = 7/2^-$ bands in ^{29}Si. The spin of the 7·139 MeV level was tentatively assigned as $11/2^+$ by Bailey *et al* (1972). Level energies are shown in units of keV.

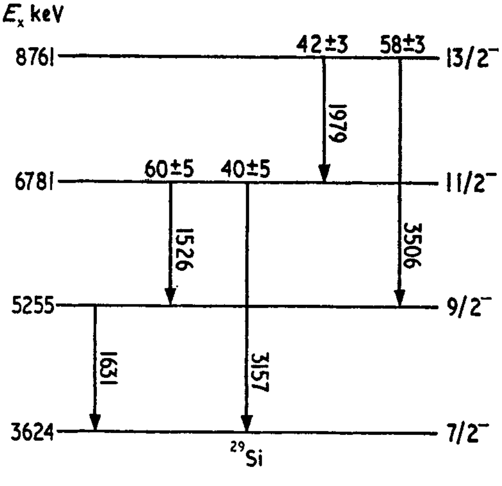

Figure 3. The decay scheme of the proposed $K^{\pi} = 7/2^-$ band in ^{29}Si. The branching ratios for the 6·781 MeV levels are due to Bailey *et al* (1972). Those for the 8·761 MeV level were measured in the present work.

except for the E2 strength of the 6·781 MeV to 3·624 MeV transition, the measured lifetime (Bailey *et al* 1972) of the 6·781 MeV level (<10 fs) being rather less than the predicted value of about 40 fs.

Table 2. Results of the present work compared with the predictions of the simple rotational model based on the properties of the 5·255 MeV state

				Experimental results		Rotational model predictions	
E_x (keV)	E_γ (keV)	J_i^π	J_f^π	E2 strength† (Wu)	δ	E2 strength (Wu)	δ
5255	1631	9/2⁻	7/2⁻	25 ± 7	$-0{\cdot}41 \pm 0{\cdot}02$‡		
6781	3157	11/2⁻	7/2⁻	> 19	0	$5{\cdot}5 \pm 1{\cdot}5$	0
6781	1526	11/2⁻	9/2⁻	> 13	$-(0{\cdot}3^{+0{\cdot}3}_{-0{\cdot}2})$	25 ± 7	$-0{\cdot}33$
8761	3506	13/2⁻	9/2⁻	> 10	0	10 ± 3	0
8761	1979	13/2⁻	11/2⁻	> 8	$-(0{\cdot}5^{+0{\cdot}5}_{-0{\cdot}2})$	22 ± 6	$-0{\cdot}34$

† The transition strengths are calculated from the lifetimes of Bailey *et al* (1972) except for the 8·761 MeV state whose lifetime was measured in the present work.

‡ This mixing ratio is a weighted mean of the data of Bardin *et al* (1970) and Main *et al* (1970).

The closeness of the levels discussed to the predictions of the simple rotational model firmly establishes a rotational rather than weak coupling interpretation of these levels. The negative sign of the mixing ratios for all three $\Delta J = 1$ in-band transitions suggests that the band has oblate deformation as predicted by Ragnarsson and Nilsson (1970) since for rotational bands, using the sign convention adopted in this work it can be shown (Main *et al* 1970) that:

$$\mathrm{Sign}\,(\delta) = -\mathrm{Sign}\left(\frac{g_k - g_r}{Q_0}\right) \qquad K \neq \tfrac{1}{2}$$

and Nakai (1971) has shown from the systematics of experimental data that in this case $(g_k - g_r)$ is expected to be negative.

The size of the intrinsic quadrupole moment for the $K^\pi = 7/2^-$ band implied by the E2 transition strength of the 5·255 MeV to 3·624 MeV decay using the mean lifetime values of Bardin *et al* (1970) and Bailey *et al* (1972) is 60 ± 15 fm^2. The value predicted by Ragnarsson and Nilsson (1970) is -62 fm^2.

We conclude that the levels discussed form a relatively pure $K^\pi = 7/2^-$ rotational band with oblate deformation. No comparable band is known in the upper part of the s–d shell.

It is interesting that the moment of inertia parameter, $\hbar^2/2\mathscr{I}$, for this band, based on a least-squares fit to the four levels is 153 keV, which is remarkably close to the rigid body value of 155 keV obtained using the deformation predicted by Ragnarsson and Nilsson (1970). The irrotational model prediction using the same deformation is 550 keV.

This work was supported by grants from the United Kingdom Science Research Council. We would like to thank Professor L L Green for his interest and encouragement in this work and to acknowledge helpful and stimulating discussions with Dr P J

Twin and Professor S G Nilsson. We thank Mr J B Reynolds for making the targets. Three of us (DAV, PEC and PJN) acknowledge the receipt of Science Research Council post graduate awards during the period of this work.

References

Bailey D C *et al* 1972 *J. Phys.* A. *Gen. Phys.* **5** 596–604
Bardin T T *et al* 1970 *Phys. Rev. Lett.* **24** 772–5
Blaugrund A E 1966 *Nucl. Phys.* **88** 501–12
Bromley D A *et al* 1957 *Can. J. Phys.* **35** 1057–85
Butler P A *et al* 1973 *Nucl. Instrum. Meth.* **108** 497–502
Cline D and Lesser P M S 1970 *Nucl. Instrum. Meth.* **82** 291–3
Lindhard J *et al* 1963 *K. danske Vidensk. Selsk., Math.-fys. Meddr* 33 No 14
Endt P M and van der Leun C 1967 *Nucl. Phys.* A **105** 1–488
Main I G *et al* 1970 *Nucl. Phys.* A **158** 364–84
Nakai K 1971 *Phys. Lett.* **34B** 269–70
Ragnarsson I and Nilsson S G 1970 *Nucl. Phys.* A **158** 155–60
Rose H J and Brink D M 1967 *Rev. mod. Phys.* **39** 306–47
Sharpey-Schafer J F *et al* 1971 *Nucl. Phys.* A **167** 602–24
Sheldon E and van Patter D M 1966 *Rev. mod. Phys.* **38** 143–86
Strutinsky V M 1967 *Nucl. Phys.* A **95** 420–42