A study of levels in ^{27}Si (using $^{28}Si(\tau,\alpha)^{27}Si$)

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A study of levels in ^{27}Si

H G Price, B T McCrone, G D Jones, M F Thomas and P J Twin

Oliver Lodge Laboratory, University of Liverpool, Oxford Street, PO Box 147, Liverpool L69 3BX, UK

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Abstract. Angular correlation measurements on levels in ^{27}Si have been made using the ^{28}Si (τ, α) ^{27}Si reaction at bombarding energies of 13·0 and 15·0 MeV. Spin restrictions and in some cases spin assignments have been made for several levels, namely 3·54 MeV ($\frac{1}{2}$, $\frac{3}{2}$) 3·81 MeV ($\frac{3}{2}$, $\frac{7}{2}$), 4·14 MeV ($\frac{1}{2}^-$, $\frac{3}{2}^-$), 4·30 MeV ($\frac{5}{2}^+$), 4·72 MeV ($\frac{5}{2}$, $\frac{7}{2}$), 5·08 MeV ($\frac{5}{2}$). Calculations based upon an excited core model have been performed in which the states in ^{27}Si are obtained from coupling quasi-hole excitations from the $d_{5/2}$, $s_{1/2}$ and $d_{3/2}$ orbitals to the ground and first excited states of a ^{28}Si core. The results of the calculations have been compared with experiment.

1. Introduction

Experimental information on the spins and parities of levels below 5 MeV in ^{27}Al is now quite extensive. There is also a large amount of data upon the electromagnetic transition rates between these levels (de Voigt *et al* 1971, Endt and van der Leun 1967). Considerably less information has been obtained (Lewis *et al* 1967, Weaver *et al* 1971) on the properties of the mirror nucleus ^{27}Si. This paper reports an angular correlation study of ^{27}Si levels below 5 MeV using the ^{28}Si (τ, α) ^{27}Si reaction. The Nilsson model (Bhatt 1962, Weaver *et al* 1971, Dehnhard 1972), the rotation–vibration interaction model (Röpke *et al* 1970, Röpke and Glattes 1972), the excited-core model (Thankappan 1966, Evers *et al* 1967) and the shell model (Wildenthal and McGrory 1973) have been used in an attempt to explain the properties of these isobars. The excited-core model and the shell model give the better account of the electromagnetic decay properties of the low lying levels. An attractive feature of the excited-core model is its simplicity; this model describes the nuclei as a $d_{5/2}$ hole coupled to the ground and 2^+ first excited state of a ^{28}Si core. However pick-up spectroscopic factors (Gove *et al* 1968, Wildenthal and Newman 1968, Kozub 1968) indicate that excitations from the $s_{1/2}$ and $d_{3/2}$ orbitals should also be included. In the present paper we extend the excited-core model to allow quasi-hole excitation from the $s_{1/2}$ and $d_{3/2}$ as well as the $d_{5/2}$ orbital. These are coupled to the ground and first excited states of a ^{28}Si core. This model was used to calculate γ ray transition rates and pick-up spectroscopic factors for levels of ^{27}Si.

2. Experimental procedure

The levels of ^{27}Si were populated via the ^{28}Si (τ, α) ^{27}Si reaction at ^{3}He bombarding energies of 13·0 and 15·0 MeV using the $^{3}He^{++}$ beam from the Liverpool University tandem accelerator. The self-supporting targets were of 80μg cm^{-2} silicon enriched to 99·6 % ^{28}Si. The α particles were detected with a 300μm annular surface barrier detector placed at 180° to the beam direction and subtending an angle of 3° at the target. The detector thickness was sufficient to stop the α particles but allowed protons produced by the (τ, p) reaction to be transmitted. Angular correlations between the α particles and the γ rays de-exciting the ^{27}Si levels were obtained by measuring the coincident γ ray yields in five 5 in × 6 in NaI(Tl) crystals placed around the target at angles of 8°, 30°, 45°, 90° and 120° in the horizontal plane ($\phi = 0$). Particular levels were selected by gating with the appropriate α particle group. Data was collected event by event and on-line analysis performed using a PDP 7 computer. Further off-line analysis was carried out with an IBM 360/65 computer. The experimental apparatus has been described in more detail elsewhere (Mulhern *et al* 1971).

The angular correlations were tested against all possible spin hypotheses for the primary levels. Spin hypotheses having minimum χ^2 values lying above the 0·1 % confidence level were rejected. Multipole mixing ratios were obtained from the fitted angular correlations and were defined using the phase convention of Rose and Brink (1967).

Branching ratios were deduced from the sin θ weighted sum spectra from the five crystals. Where possible, branching ratios were deduced from the means of the weighted yields of the primary and secondary decays.

To improve statistics, for states with low γ ray yields, the spectra from runs at 13·0 and 15·0 MeV were added together. This procedure is justified, since, to an excellent approximation, only one substate of the primary levels is populated.

3. Results

The results for the levels up to the 2·648 MeV $\frac{5}{2}^+$ level have already been presented (Main *et al* 1971). We therefore discuss here only the higher energy levels excited in this reaction. The coincidence α particle spectrum at a bombarding energy of 13·0 MeV is shown in figure 1. A summary of the results is given in table 1 and a summary of the γ ray transitions is shown in figure 2.

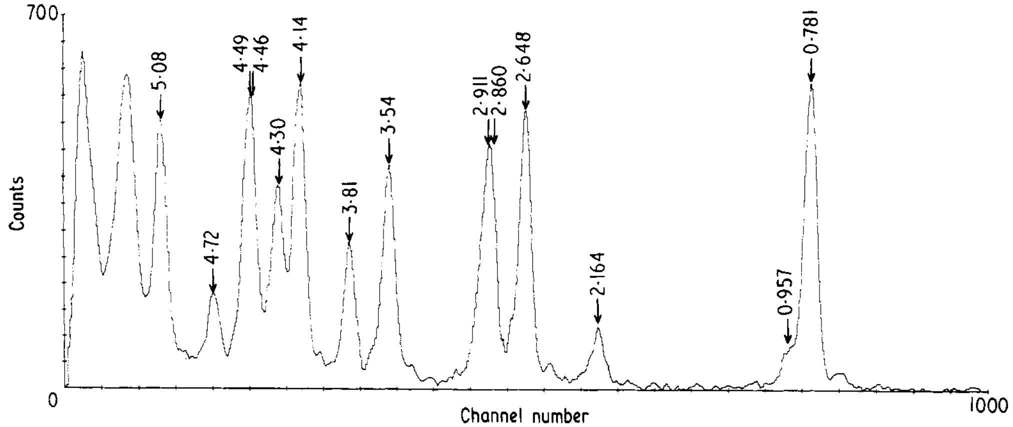

Figure 1. The coincidence α particle spectrum at a ^{3}He bombarding energy of 13·0 MeV.

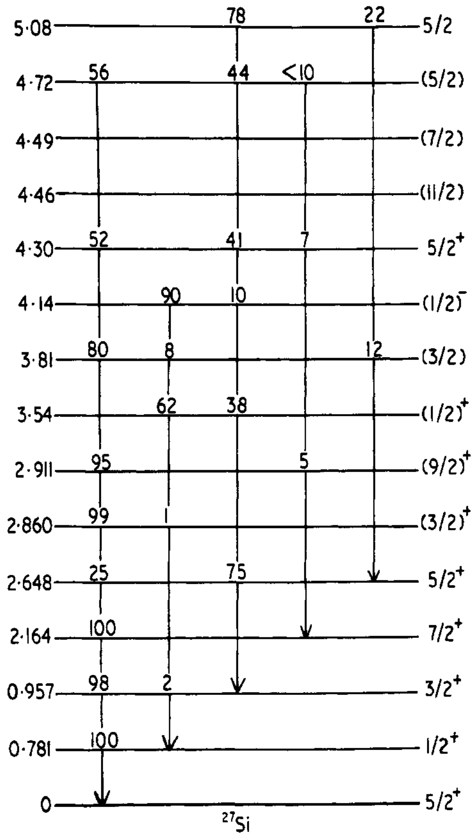

Figure 2. A summary of the γ ray transitions between the levels of ^{27}Si up to 5·08 MeV.

3.1. The 2·86 and 2·91 MeV levels

In the present work these levels could not be resolved in the α particle spectrum. Changes in bombarding energy resulted in some change in the relative excitation of the two levels but insufficient to produce any conclusive result on either level. However the results obtained from setting narrow markers on either side of the composite α particle peak were consistent with the results of previous angular correlation measurements on this doublet obtained with a position sensitive detector in the focal plane of a magnetic spectrograph (Holden *et al* 1971).

3.2. The 3·54 MeV level

This level decays entirely through the 0·781 and 0·957 MeV levels. Unfortunately the two primary γ rays are only partially resolved in the NaI(Tl) spectra so that angular correlations of the individual primaries could not be obtained. However the correlations of the composite primary γ ray peak and both secondary γ rays are isotropic within errors so that spin $\frac{1}{2}$ for the 3·54 MeV level is indicated although $J = \frac{3}{2}$ cannot be excluded. The mirror level in ^{27}Al at 3·679 MeV has been assigned a J^{π} of $\frac{1}{2}^{+}$ (Endt and van der Leun 1967).

Table 1. A summary of the experimental results of the present and previous work. Lifetimes are from Hagen *et al* (1972). Branching and mixing ratios are from the present work (see text), Main *et al* (1971) and Holden *et al* (1971). In case of a spin ambiguity the quoted mixing ratio refers to the most probable spin assignment

E_x (MeV)	J^π	τ (fs)	Branching ratio (%)	Mixing ratio
0·781	$\frac{1}{2}^+$	$(50 \pm 6) \times 10^3$	$100 \rightarrow 0$	
0·957	$\frac{3}{2}^+$	1824 ± 153 fs	$98 \rightarrow 0$	$-0·25 \pm 0·07$
			$2 \rightarrow 0·781$	
2·164	$\frac{7}{2}^+$	$50·6 \pm 6·4$	$100 \rightarrow 0$	$0·33 \pm 0·04$
2·648	$\frac{5}{2}^+$	$22·3 \pm 7·1$	$25 \rightarrow 0$	$0·38 \pm 0·08$
			$75 \rightarrow 0·957$	$0·09 \pm 0·03$
2·860	$\frac{3}{2}, (\frac{5}{2}, \frac{7}{2})$	< 10	$99 \rightarrow 0$	$\sim 0·0$
			$1 \rightarrow 0·781$	
2·911	$(\frac{3}{2}, \frac{5}{2})\, \frac{9}{2}$	$75·9 \pm 7·6$	$95 \rightarrow 0$	$\sim 0·0$
			$5 \rightarrow 2·164$	
3·54†	$\frac{1}{2}, (\frac{3}{2})$		$62 \pm 4 \rightarrow 0·781$	
			$38 \pm 4 \rightarrow 0·957$	
3·81†	$\frac{3}{2}, (\frac{7}{2})$		$80 \pm 4 \rightarrow 0$	$0·00 \pm 0·05$
			$8 \pm 6 \rightarrow 0·781$	
			$12 \pm 8 \rightarrow 2·648$	$1·0^{+1·1}_{-0·5}$
4·14†	$\frac{1}{2}^- (\frac{3}{2}^-)$		$90 \pm 4 \rightarrow 0·781$	
			$10 \pm 4 \rightarrow 0·957$	
4·30†	$\frac{5}{2}^+$		$52 \pm 4 \rightarrow 0$	$-0·36 \pm 0·26$
			$41 \pm 8 \rightarrow 0·957$	$-0·21 \pm 0·07$
			$7 \pm 4 \rightarrow 2·164$	$-0·09 \pm 0·16$
4·46	$(\frac{11}{2}^+)$			
4·49	$(\frac{7}{2}^+)$			
4·72†	$\frac{5}{2}, (\frac{7}{2})$		$56 \pm 8 \rightarrow 0$	$-0·36 \pm 0·30$
			$44 \pm 8 \rightarrow 0·957$	$< -1·8$
			$< 10 \rightarrow 2·164$	
5·08†	$\frac{5}{2}$		$78 \pm 8 \rightarrow 0·957$	$-0·07 \pm 0·04$
			$22 \pm 8 \rightarrow 2·64$	$(7·7^{+49·1}_{-3·8})$
				or
				$0·04 \pm 0·20$

† Present work.

Branching ratios obtained from the secondary γ rays were 62% to the 0·781 MeV state and 38% to the 0·957 MeV state. This result is in good agreement with the work of Lewis *et al* (1967).

3.3. The 3·81 MeV level

The coincidence γ ray spectrum for this level is shown in figure 3. The level decays to the ground, 0·781 and 2·648 MeV states. The decay to the 0·781 MeV level is indicated by

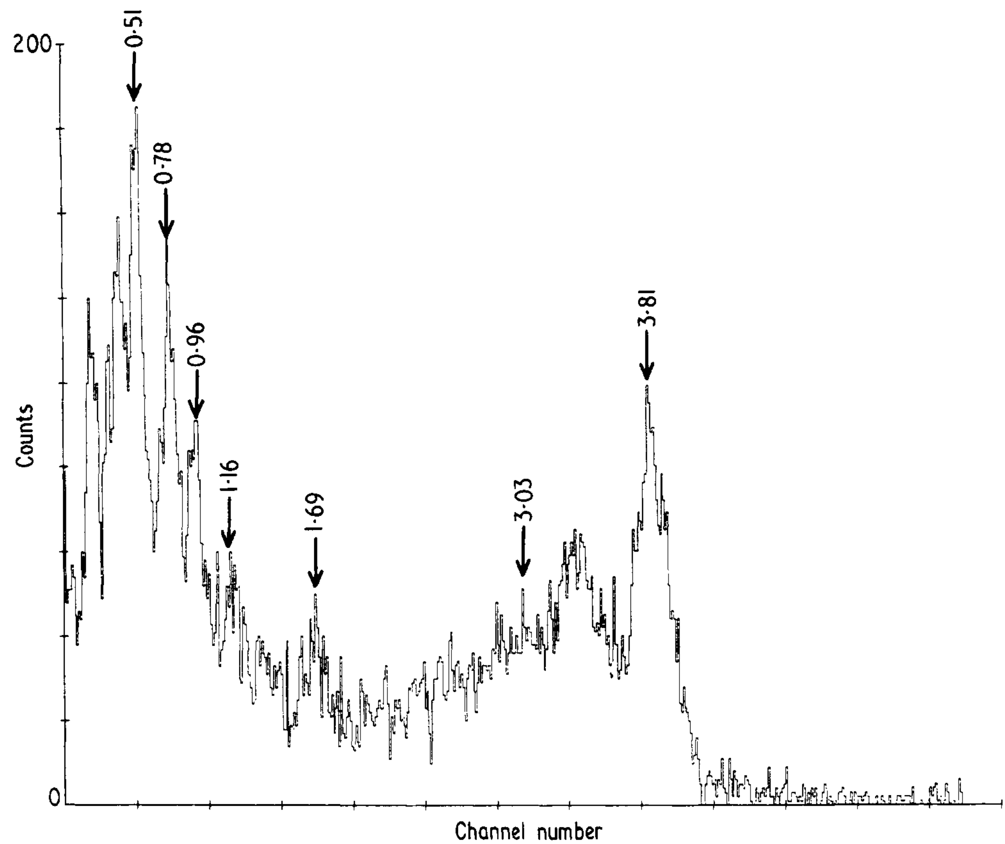

Figure 3. The sin θ summed γ ray coincidence spectrum for the 3·81 MeV level. The 'peaks' below 0·51 MeV γ ray are a result of the different discriminator levels on the individual crystals.

the presence of a 0·781 MeV γ ray, the primary γ ray being too weak to be clearly seen. The branching ratios were 80 % to ground, 8 ± 6 % to the 0·781 MeV level and 12 ± 8 % to the 2·648 MeV level.

The angular correlation of the ground state γ ray allowed spin possibilities of $\frac{3}{2}$ or $\frac{7}{2}$ as can be seen from figure 4. A $\frac{7}{2}$ spin assignment implies an octupole transition to the $\frac{1}{2}^+$ 0·781 MeV level. The lifetime of the 3·81 MeV state is unknown so that a $\frac{7}{2}$ assignment cannot be excluded. However it can be mentioned that in order to have an octupole strength of 1 Wu, the lifetime of the state is 2 ns implying a dipole strength of 10^{-7} Wu for the ground state transition. It therefore seems that a $\frac{7}{2}$ assignment for the 3·81 MeV is unlikely and a spin assignment of $\frac{3}{2}$ is favoured. The multipole mixing ratio assuming a J assignment of $\frac{3}{2}$ is shown in table 1. The mirror level in ^{27}Al at 3·957 MeV has most probably $J = \frac{3}{2}$ (Sheppard and van der Leun 1967, Carter *et al* 1969b).

3.4. The 4·14 MeV level

This level decays entirely through the 0·781 and 0·957 MeV levels with a branching ratio of 90 % and 10 % respectively. The angular correlations of the composite primary

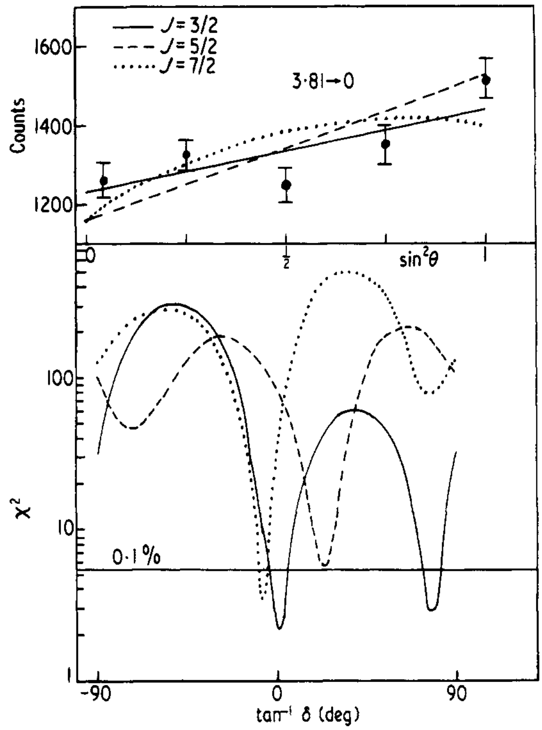

Figure 4. The angular correlation of the ground state decay from the 3·81 MeV level together with the best fits for various hypotheses. A plot χ^2 against $\tan^{-1}\delta$ is also shown.

and the two secondary γ rays are isotropic within errors indicating that a J of $\frac{1}{2}$ is likely although a J of $\frac{3}{2}$ cannot be excluded.

This level has been observed in ^{28}Si (p, d) ^{27}Si with $l = 1$ neutron pick-up and so has negative parity (Kozub 1968). The mirror level in ^{27}Al has $J^\pi = \frac{1}{2}^-, \frac{3}{2}^-$ (Wildenthal and Newman 1968). The present results are consistent with this assignment for the level in ^{27}Si.

3.5. The 4.30 MeV level

This level decays to the ground, 0·957 MeV and 2·164 MeV states. The branching ratios were measured to be 52 % to ground, 41 % to the 0·957 MeV level and 7 % to the 2·164 MeV level. The angular correlation of the ground state γ ray could be fitted (figure 5) with spin possibilities of $\frac{5}{2}$ or $\frac{7}{2}$. The angular correlation of the decay to the 0·957 MeV level excluded the $\frac{7}{2}$ possibility. Also this level has been observed to be excited with $l = 2$ neutron pick-up in the ^{28}Si(p, d)^{27}Si reaction (Kozub 1968) so that a J of $\frac{7}{2}$ is excluded. A unique J^π assignment of $\frac{5}{2}^+$ can therefore be made for this level and multipole mixing ratios are shown in table 1.

The mirror level in ^{27}Al at 4·411 MeV has most probably (Sheppard and van der Leun 1967, Wildenthal and Newman 1968) a J^π of $\frac{5}{2}^+$.

3.6. The 4·46 and 4·49 MeV levels

These levels were unresolved in the particle spectrum and no uncontaminated data

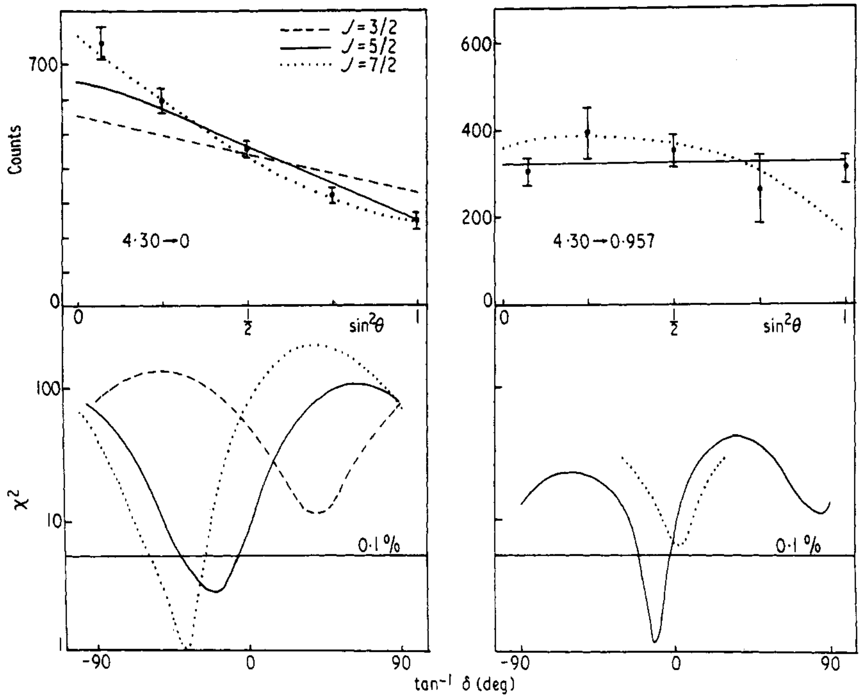

Figure 5. The angular correlation of the γ decay from the 4·30 MeV level together with the best fits for various spin hypotheses. Plots of χ^2 against $\tan^{-1}\delta$ are also shown. If a spin hypothesis involves an octupole admixture then only mixing ratios with $\tan^{-1}\delta$ less than 30° are considered.

could be extracted on either level even by changing beam energy. The doublet decays to the ground, 2·164 MeV and 2·86–2·91 MeV levels. No appreciable difference could be seen corresponding to windows set on either side of the peak so that the branching ratios of the individual levels could not be extracted. The mirror levels in ^{27}Al have been assigned J of $\frac{11}{2}$ and $\frac{7}{2}$. Their decay is 85% to the 2·212 MeV $\frac{7}{2}^+$ level and 15% to the 3·006 MeV $\frac{9}{2}^+$ level for the $\frac{11}{2}^+$ state and 77% to the ground and 23% to the 2·212 MeV $\frac{7}{2}^+$ level for the $\frac{7}{2}^+$ state (Carter *et al* 1969a, de Voigt *et al* 1971). The result for the ^{27}Si doublet is consistent with these decay modes.

3.7. *The 4·72 MeV level*

This level decays to the ground and 0·957 MeV states. The branching ratios were measured to be 56% to ground and 44% to the 0·957 MeV level.

The angular correlations of the γ rays to the ground and 0·957 MeV states allowed spin possibilities of $\frac{5}{2}$ or $\frac{7}{2}$ (figure 6) for the 4·72 MeV level. The mixing ratio for the decay to the 0·957 MeV $\frac{3}{2}^+$ level if a spin assignment of $\frac{7}{2}$ is made, is $-0{\cdot}47^{+0{\cdot}26}_{-0{\cdot}62}$ indicating appreciable octupole admixture. The lifetime of the 4·72 MeV level is unknown, however for the decay to the 0·957 MeV level to have an octupole strength of 1 Wu, the lifetime would have to be about 10^{-10} s. This would imply a dipole strength of the order of 10^{-6} Wu for the ground state transition. It would therefore seem that a spin assignment of $\frac{5}{2}$ is somewhat favoured. Multipole mixing ratios assuming a J of $\frac{5}{2}$ for the 4·72 MeV

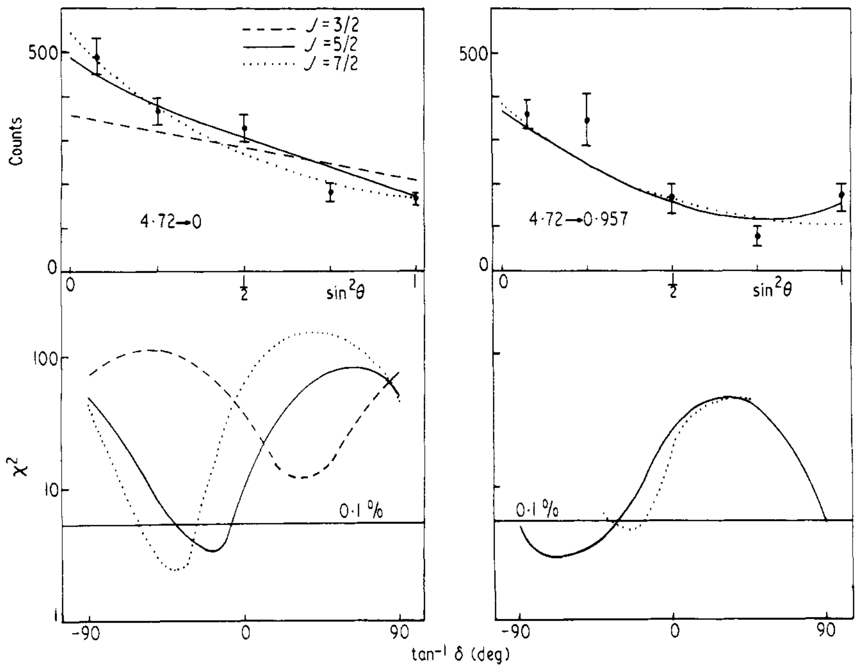

Figure 6. The angular correlation of the γ decay from the 4·72 MeV level together with the best fits for various spin hypotheses. Plots of χ^2 against $\tan^{-1}\delta$ are also shown. If a spin hypothesis involves an octupole admixture then only mixing ratios with $\tan^{-1}\delta$ less than 30° are considered.

level are shown in table 1. The mirror level in ^{27}Al at 4·812 MeV has been assigned (Endt and van der Leun 1967) a J^π of $\frac{5}{2}^{(+)}$.

3.8. The 5·08 MeV level

This level decays through the 0·957 and 2·164 MeV states, the branching ratios being 78% and 22% respectively. Fitting the angular correlations of the 4·12 MeV transition to the 0·957 MeV level and the subsequent 0·957 MeV γ ray simultaneously, a unique spin assignment of $\frac{5}{2}$ was obtained for the 5·08 MeV level as can be seen from figure 7. The mixing ratios are shown in table 1.

4. Discussion

Several models have been used to describe the properties of the low lying levels of ^{27}Al and ^{27}Si, among them the excited core model, the rotation–vibration interaction model and the Nilsson model. The simple Nilsson model describes (Bhatt 1962) the nuclei as a particle strongly coupled to a deformed ^{26}Mg core, rotational bands being built on the intrinsic states so obtained. This model predicts the energies of the low lying levels well but gives poor general agreement with the γ ray transition rates. The rotation–vibration interaction model of ^{27}Al (Röpke *et al* 1970) builds rotational bands on the ground state of ^{27}Al and on the states obtained by coupling the ground state configuration of ^{27}Al to the 2^+ γ vibrational state in ^{26}Mg. This model gives good agreement with the E2

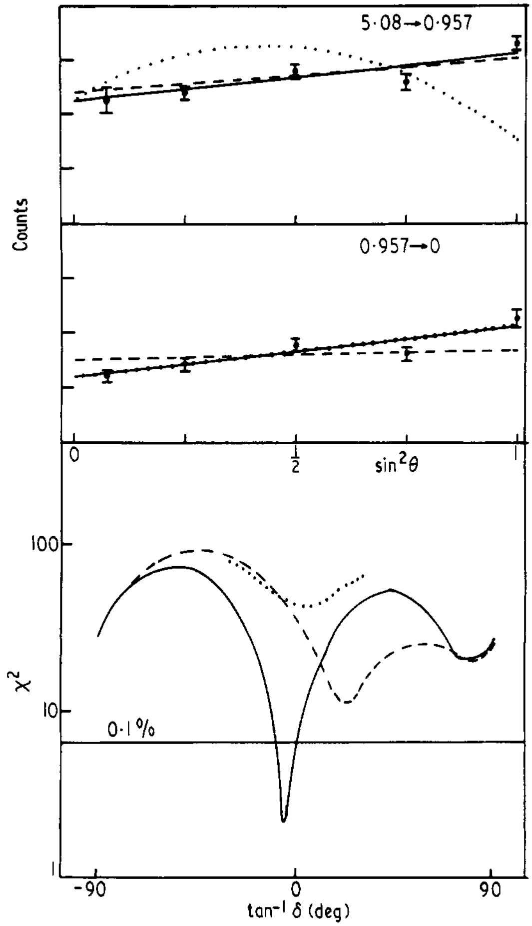

Figure 7. The angular correlation of the primary and secondary transitions from the 5·08 MeV to 0·957 MeV levels together with the best simultaneous fits for various spin hypotheses. A plot of χ^2 against $\tan^{-1}\delta$ is also shown, again only octupole mixing ratios for which $\tan^{-1}\delta < 30°$ are considered. The full line refers to a $\frac{5}{2}$ hypothesis, the broken line to a $\frac{3}{2}$ hypothesis and the dotted line to a $\frac{7}{2}$ hypothesis for the 5·08 MeV level.

transition rates of ^{27}Al but not the M1 transition rates or the pick-up spectroscopic factors. Probably one of the more successful models for the γ ray transition rates of the low lying levels of ^{27}Al up to the $\frac{9}{2}^+$ level at 3·006 MeV is the excited core model (Thankappan 1966). In its simplest form it describes the levels of ^{27}Si and ^{27}Al as the coupling of a $d_{5/2}$ hole to the ground and 2^+ first excited state of ^{28}Si. Its main drawbacks are that it reproduces the energy level scheme only if sufficient terms in the tensor expansion of the hole–core interaction are included in which case a trivial fit is obtained which even then fails to reproduce the second $\frac{3}{2}^+$ state. Furthermore correct pick-up spectroscopic factors are not predicted. This results from the neglect of $s_{1/2}$ and $d_{3/2}$ holes in the calculations. A refinement of this model was carried out by Evers *et al* (1967) for ^{27}Al by allowing a $d_{3/2}$ hole coupled to the ground state of ^{28}Si admixture in the $\frac{3}{2}^+$ wavefunctions. The wavefunctions were obtained by fitting to the observed M1 and E2 strengths. This model gave better agreement with the experimental M1 strengths but overestimated the M1 strength of the transition between the second excited state ($\frac{3}{2}^+$)

and the first excited state ($\frac{1}{2}^+$). This model again failed to reproduce the pick-up spectroscopic factors and could only reproduce the energy level scheme up to the $\frac{9}{2}^+$ level by including sufficient terms in the hole–core interaction thereby introducing extra adjustable parameters in calculating the energies.

In this paper we extend the excited core model to allow quasi-hole excitation from the $s_{1/2}$ and $d_{3/2}$ as well as the $d_{5/2}$ orbital. These are coupled to the 0^+ ground state and 2^+ first excited state at 1·77 MeV in a ^{28}Si core. In our case we have limited the core–particle interaction used by Thankappan (1966) and Thankappan and True (1965) to be of the form

$$H_{\text{int}} = -\eta \boldsymbol{Q}_{\text{c}} \cdot \boldsymbol{Q}_{\text{p}}$$

where $\boldsymbol{Q}_{\text{c}}$ is the quadrupole moment operator of the core and $\boldsymbol{Q}_{\text{p}}$ that of the particle and η is the strength of the interaction.

As usual the basis states are taken as $|J_{\text{c}}jJ\rangle$ where J_{c} is the angular momentum of the core, j that of the particle and J the total angular momentum obtained by coupling J_{c} and j. These basis states diagonalize the hamiltonian $(H_{\text{c}}+H_{\text{p}})$ where H_{c} is the hamiltonian of the core and H_{p} that of the particle.

The matrix element of H_{int} between two basis states is

$$\langle J_{\text{c}}' j' JM|H_{\text{int}}|J_{\text{c}}jJM\rangle = -\eta W(2j'J_{\text{c}}J\,;jJ_{\text{c}}')\langle J_{\text{c}}'\|\boldsymbol{Q}_{\text{c}}\|J_{\text{c}}\rangle\langle j'\|\boldsymbol{Q}_{\text{p}}\|j\rangle(U_jU_{j'}-V_jV_{j'}).$$

This differs from the matrix elements given by Thankappan and True (1965) by the factor $(U_jU_{j'}-V_jV_{j'})$ because of the quasi-particle nature of the states j and j' (Castel *et al* 1971) where U_j and V_j are the quasi-particle and quasi-hole amplitudes of state j. These were obtained from the results of stripping and pick-up reactions on ^{28}Si (Kozub 1968, Schiffer *et al* 1966, Gove *et al* 1968). The quasi-hole amplitudes used were $V_{5/2}^2 = 0{\cdot}70$, $V_{1/2}^2 = 0{\cdot}40$ and $V_{3/2}^2 = 0{\cdot}25$. In so doing the modification of these amplitudes due to blocking is not considered, eg see Nilsson and Prior (1961).

The energy levels and wavefunctions of ^{27}Si were obtained by diagonalizing the total hamiltonian

$$H = H_{\text{c}}+H_{\text{p}}+H_{\text{int}}.$$

The single particle matrix elements $\langle j'\|\boldsymbol{Q}_{\text{p}}\|j\rangle$ were evaluated directly, the matrix elements of r^2 which appear in this evaluation being calculated using harmonic oscillator wavefunctions where $v = 41M/\hbar^2A^{1/3} = 0{\cdot}333F^{-2}$. The two core matrix elements $\chi_1 = \eta\langle 0\|\boldsymbol{Q}_{\text{c}}\|2\rangle$ and $\chi_2 = \eta\langle 2\|\boldsymbol{Q}_{\text{c}}\|2\rangle$ and the quasi-particle energy differences $E(s_{1/2})-E(d_{5/2})$ and $E(d_{3/2})-E(d_{5/2})$ were taken as adjustable parameters. These four parameters were chosen by least squares fitting the theoretical levels to the experimental levels of ^{27}Si up to and including the probable $\frac{1}{2}^+$ state at 3·54 MeV. In the cases where an experimental spin ambiguity occurred for a level, the spin was taken as that of the mirror ^{27}Al level.

The values of the parameters which gave the best fit to the energy levels were $E(s_{1/2})-E(d_{5/2}) = 0{\cdot}72$ MeV, $E(d_{3/2})-E(d_{5/2}) = 1{\cdot}73$ MeV, $\chi_1 = 2{\cdot}4$ MeV F^{-2} and $\chi_2 = -1{\cdot}84$ MeV F^{-2}. The quasi-particle energies are reasonably consistent with the results of pick-up reactions on ^{28}Si. The sign of χ_1 was chosen to give a positive quadrupole moment for the ground state of ^{27}Si and ^{27}Al in agreement with experiment. The energy levels of ^{27}Si predicted by this calculation are shown in figure 8 opposite the experimental results. It can be seen that good agreement is obtained. The $\frac{1}{2}^-$ and $\frac{11}{2}^+$ states have not been shown as these would not be predicted by the model.

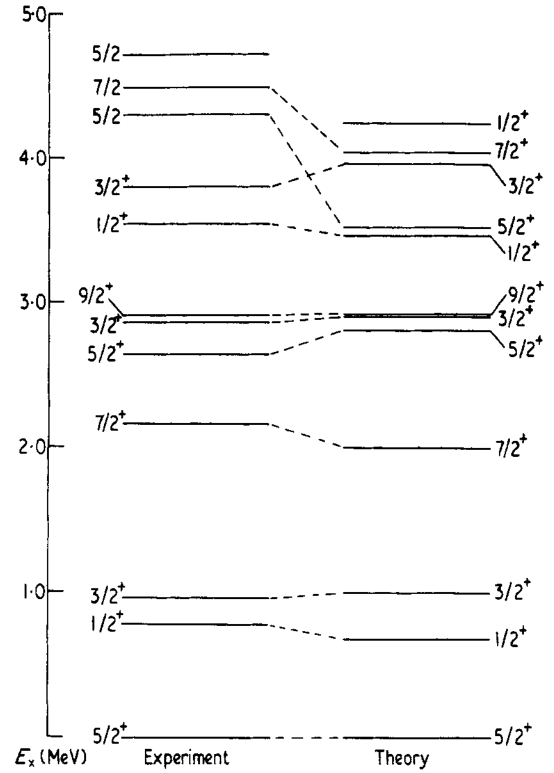

Figure 8. The experimental and calculated level scheme of ^{27}Si. The possible $\frac{1}{2}^-$ and $\frac{11}{2}^+$ states have been excluded from the experimental scheme as these would not be predicted by the model. In the case of an experimental spin ambiguity the most probable spin assignment has been used.

The wavefunctions obtained from the energy level fit were used in calculating B(E2) and B(M1) values together with pick-up spectroscopic factors from ^{28}Si for the ^{27}Si levels. In the B(E2) calculations the core matrix element $\langle 0 \| e_c \boldsymbol{Q}_c \| 2 \rangle$ was obtained from the observed B(E2) of 65 $e^2 f^4$ for the decay of the first excited state of ^{28}Si, while the matrix element $\langle 2 \| e_c \boldsymbol{Q}_c \| 2 \rangle$ was taken as $(\chi_2/\chi_1)\langle 0 \| e_c \boldsymbol{Q}_c \| 2 \rangle$ where χ_2 and χ_1 were taken as the values used in the energy level calculation. The effective charge of the neutron was taken as zero. In the B(M1) calculations the single particle matrix elements were multiplied by the quasi-particle factor $(U_j U_{j'} + V_j V_{j'})$ (Castel *et al* 1971). The neutron g factors were taken as those for a free neutron $g_l = 0$ and $g_s = -3{\cdot}82$ while the core g factor was taken as zero. Spectroscopic factors for pick-up from ^{28}Si were given by

$$S = (2j+1)V_j^2 A_{|0jj\rangle}^2$$

where $A_{|0jj\rangle}$ is the amplitude of the $|0jj\rangle$ component in the wavefunction of the level in question. The present calculations only produce relative pick-up spectroscopic factors of course, the occupation numbers of the single particle orbitals of the core being input quantities obtained from experiment as mentioned previously.

The results of these calculations are shown in tables 2, 3 and 4. In general the E2 and M1 strengths and spectroscopic factors agree reasonably well with experiment. The serious discrepancies are the very low values for the E2 transition rates from the 0·957

Table 2. The experimental and calculated single nucleon pick-up spectroscopic factors from ^{28}Si

E_x (MeV)		J^π	Experiment		Calculated
^{27}Si	^{27}Al		^{27}Si†	^{27}Al‡	
0	0	$\frac{5}{2}^+$	3·45	3·76	3·09
0·78	0·84	$\frac{1}{2}^+$	0·64	0·49	0·60
0·96	1·01	$\frac{3}{2}^+$	0·34	0·56	0·58
2·65	2·73	$\frac{5}{2}^+$	0·47	0·61	0·61
2·87	2·98	$\frac{3}{2}^+$	0·81	$\leqslant$0·40	0·01
3·54	3·68	$\frac{1}{2}^+$		$\leqslant$0·02	0·005
4·41	4·41	$\frac{5}{2}^+$	0·34	0·35	0·48

† $^{28}Si(p, d)\,^{27}Si$ (Kozub 1968).
‡ $^{28}Si(d, {}^3He)\,^{27}Al$ (Wildenthal and Newman 1968).

Table 3. Calculated and experimental B(E2) and B(M1) values for transitions from levels in ^{27}Si whose lifetimes are known

Transition	J_i^π	J_f^π	B(E2) (e^2f^4)		B(M1) ($\mu_0^2 \times 10^{-2}$)	
			Experiment	Calculated	Experiment	Calculated
0·781 → 0	$\frac{1}{2}^+$	$\frac{5}{2}^+$	55 ± 7	1·5	—	—
0·957 → 0	$\frac{3}{2}^+$	$\frac{5}{2}^+$	33 ± 18	0·0	3·2 ± 0·3	41·3
0·957 → 0·781	$\frac{3}{2}^+$	$\frac{1}{2}^+$			<12	0·6
2·164 → 0	$\frac{7}{2}^+$	$\frac{5}{2}^+$	32·7 ± 8·5	74·5	9·9 ± 1·3	6·4
2·648 → 0	$\frac{5}{2}^+$	$\frac{5}{2}^+$	8·5 ± 4·0	16·9	3·0 ± 1·0	1·1
2·648 → 0·957	$\frac{5}{2}^+$	$\frac{3}{2}^+$	15·8 ± 12·0	1·1	39·1 ± 12·4	77·2
2·860 → 0	$\frac{3}{2}^+$	$\frac{5}{2}^+$		34·4	>24·0	19·5
2·911 → 0	$\frac{9}{2}^+$	$\frac{5}{2}^+$	49·0 ± 5·0	35·0	—	—
2·911 → 2·164	$\frac{9}{2}^+$	$\frac{7}{2}^+$		14·3	<10	13·3

MeV ($\frac{3}{2}^+$) and 0·781 MeV ($\frac{1}{2}^+$) states to ground and the small value for the pick-up spectroscopic factor for the 2·86 MeV ($\frac{3}{2}^+$) level. These low values for the E2 strengths from the first and second excited states are essentially caused by the small amplitudes of the $|2\frac{5}{2}\frac{1}{2}\rangle$ and $|2\frac{5}{2}\frac{3}{2}\rangle$ components in the wavefunctions of these respective states. This in turn results from the low values of the quasi-particle factors $(U_{5/2}U_{1/2} - V_{5/2}V_{1/2})$ and $(U_{5/2}U_{3/2} - V_{5/2}V_{3/2})$ appearing in the particular off-diagonal matrix elements of the hamiltonian. As such, these factors are somewhat sensitive to the precise value of the quasi-particle amplitudes. This effect has been met by Castel *et al* (1971) in their calculations on ^{33}S. One would expect that a more detailed calculation, in which the quasi-particle amplitudes are more rigorously taken into account might remove these discrepancies in the E2 strengths. The low value for the pick-up spectroscopic factor for the 2·86 MeV ($\frac{3}{2}^+$) level is caused by the fact that the calculations predict it to be mainly a core excitation state with a $|2\frac{5}{2}\frac{3}{2}\rangle$ configuration. With the simple core–particle interaction used in these calculations this discrepancy cannot be remedied without the loss of the single hole nature of the 0·781 MeV ($\frac{1}{2}^+$) state, the $s_{1/2}$ hole state then being predicted to be the 3·54 MeV ($\frac{1}{2}^+$) state. This then indicates that a more complicated interaction is necessary.

Table 4. Comparison between experimental and calculated branching ratios and multipole mixing ratios of transitions in ^{27}Si

E_x (MeV)	J^π	Experimental		Calculated	
		Branching ratio (%)	Mixing ratio	Branching ratio (%)	Mixing ratio
0·957	$\frac{3}{2}^+$	98 → 0	−0·25 ± 0·07	100 → 0	0·00
		2 → 0·781			
2·164	$\frac{7}{2}^+$	100 → 0	0·33 ± 0·04	100 → 0	0·60
2·648	$\frac{5}{2}^+$	25 → 0	0·38 ± 0·08	10 → 0	−0·84
		75 → 0·957	0·09 ± 0·03	90 → 0·957	0·02
2·860	$\frac{3}{2}^+$	99 → 0	0·0	81 → 0	−0·30
		1 → 0·781		5 → 0·781	
				14 → 0·957	
2·911	$\frac{9}{2}^+$	95 → 0	0·0	90 → 0	0
		5 → 2·164		10 → 2·164	0·06
3·54	$\frac{1}{2}^+$			7 → 0	
		62 → 0·781		62 → 0·781	0
		38 ± 4 → 0·957		26 → 0·957	−0·22
				5 → 2·860	
3·81	$\frac{3}{2}^+$	80 ± 4 → 0	0·00 ± 0·05	83 → 0	0·10
		8 ± 6 → 0·781		11 → 0·781	∞
		12 ± 8 → 2·648	$1·0^{+1·1}_{-0·5}$	6 → 2·648	0·03
4·30	$\frac{5}{2}^+$	52 ± 4 → 0	−0·36 ± 0·26	41 → 0	−0·52
		41 ± 8 → 0·957	−0·21 ± 0·07	2 → 0·957	∞
				15 → 0·781	
		7 ± 4 → 2·164	−0·09 ± 0·16	42 → 2·164	−0·05

It is worthwhile to point out that the excited core model, in the form used in the present calculations is essentially equivalent to the intermediate coupling anharmonic vibrational model in which an odd particle is coupled to one phonon. The same results would be obtained with this latter model with a suitable choice of its parameters.

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