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1973 J. Phys. A: Math. Nucl. Gen. 6 L15

(http://iopscience.iop.org/0301-0015/6/2/004)

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

LETTER TO THE EDITOR

Gamma-ray linear polarization measurements in ^{33}S

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MS received 9 January 1973

Abstract. The reaction $^{30}Si(\alpha, n)^{33}S$ was used to populate levels in ^{33}S at α particle energies of 7·7 MeV and 9·8 MeV. Gamma rays in ^{33}S were detected in a Ge(Li)–NaI(Tl) escape-suppressed spectrometer and a three Ge(Li) Compton polarimeter. The analysis of angular distributions and experimental linear polarizations of γ rays gave spin and parity assignments of $\frac{5}{2}^+$, $\frac{5}{2}^+$, $\frac{7}{2}^+$ and $\frac{11}{2}^-$ for the levels at 2868, 4050, 4096 and 4868 keV respectively.

Recent work in this laboratory (Carr *et al* 1973) has given much information on the properties of the low lying nuclear states in ^{33}S by measuring their lifetimes and the angular distributions of the de-exciting γ rays. However, some spin ambiguities remained which made tentative the comparison with predictions from nuclear models. In this work unique spin assignments have been made to four levels in ^{33}S by measuring the linear polarizations of the emitted γ rays simultaneously with their angular distributions.

The 2868 keV level in ^{33}S was populated by the $^{30}Si(\alpha, n)^{33}S$ reaction at $E_\alpha = 7{\cdot}7$ MeV, and the 4050, 4096 and 4868 keV levels were populated at $E_\alpha = 9{\cdot}8$ MeV. The target comprised a 800 μg cm^{-2} layer of silicon (enriched to 95% in ^{30}Si) evaporated onto a gold backing. The intensities of the main branch γ rays were measured at five angles θ between 0° and 90° to the beam direction with a Ge(Li)–NaI(Tl) escape-suppressed spectrometer (Sharpey-Schafer *et al* 1971). The reaction rate was monitored by observation of the decay of the $J^\pi = \frac{1}{2}^+$ first excited state of ^{33}S. The linear polarizations of the γ rays emitted at 90° to the incoming beam, $P_E(\theta = 90°)$, were determined simultaneously with their angular distributions using a three Ge(Li) Compton polarimeter, previously calibrated with γ rays of known polarization (Butler *et al* 1973). The relative populations of the substates of the levels were calculated using the statistical model program MANDY (Sheldon and Van Patter 1966). A summary of the angular distribution and polarization measurements is given in table 1.

The measured angular distributions and the calculated substate populations yielded in all cases ambiguous values for the spins and mixing ratios (δ) for the levels and their transitions. The values were consistent with those reported by Carr *et al* (1973), who made measurements on the 2868, 4050 and 4868 keV levels. For the 4096 keV level, which decays mainly to the 1968 keV level ($J^\pi = \frac{5}{2}^+$) as well as to the ground state, spin hypotheses of $\frac{3}{2}$,$\frac{5}{2}$, and $\frac{7}{2}$ gave acceptable fits to the angular distribution of the 2128 keV γ ray. The lifetime of the 4096 keV level has been measured by Carr

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Table 1. A summary of the experimental measurements, deduced level spins, γ ray multipole mixing ratios and transition strengths

E_x (keV)	E_α (MeV)	τ† (fs)	E_γ (keV)	Measured a_2	Measured a_4	J_i^π	J_f^π	δ‡	Predicted $P_T(\theta = 90°)$	Measured $P_E(\theta = 90°)$	Transition strength $\lvert M1\rvert^2$ (mWu)	Transition strength $\lvert E2\rvert^2$ (Wu)
2868	7·7	34±14	2868	−0·09±0·01	0·00±0·01	$\frac{5}{2}^+$	$\frac{3}{2}^+$	0·14±0·02	−0·57±0·02	−0·65±0·17	39^{+27}_{-12}	$0·4^{+0·4}_{-0·2}$
						$\frac{3}{2}^+$	$\frac{3}{2}^+$	0·34±0·02	+0·50±0·01			
						$\frac{3}{2}^+$	$\frac{3}{2}^+$	11±3	+0·04±0·02			
4050	9·8	300±80	2082	0·32±0·03	−0·22±0·03	$\frac{9}{2}^+$	$\frac{5}{2}^+$	0	+0·75	+0·78±0·13		9±3
						$\frac{5}{2}^+$	$\frac{5}{2}^+$	−2·2±0·8	+0·34±0·03			
4096	9·8	45±12	2128	0·03±0·01	0·03±0·01	$\frac{7}{2}^+$	$\frac{5}{2}^+$	−0·19±0·02	−0·62±0·02	−0·73±0·11	70±20	2·5±1·1
						$\frac{7}{2}^-$	$\frac{5}{2}^+$	−0·19±0·02	+0·62±0·02			
						$\frac{5}{2}^+$	$\frac{5}{2}^+$	0·32±0·03	+0·61±0·02			
						$\frac{3}{2}^\pm$	$\frac{5}{2}^+$	0·16±0·04	∓0·14±0·02			
						$\frac{3}{2}^\pm$	$\frac{5}{2}^+$	2·5±0·4	∓0·38±0·01			
4868	9·8	350±90	1933	0·41±0·02	−0·27±0·02	$\frac{11}{2}^-$	$\frac{7}{2}^-$	0	+0·75	+0·56±0·15		15±4
						$\frac{7}{2}^-$	$\frac{7}{2}^-$	1·28±0·09	−0·41±0·05			

† Carr *et al* (1973).
‡ The sign convention of Rose and Brink (1967) is used.

et al (1973) to be 45 ± 12 fs. An M2 transition strength of greater than 120 Wu (Weisskopf single particle units) for the 2128 keV transition excludes the possibility $J^\pi = \frac{5}{2}^-$ for this level. Furthermore, the possibility of $J^\pi = \frac{3}{2}^+$, $\delta = 2{\cdot}5$ is unlikely since the E2 transition strength would be greater than 40 Wu.

For all four levels, the experimental linear polarizations $P_E(\theta = 90°)$ were compared with the predicted values $P_T(\theta = 90°)$ for each of the spin and δ possibilities. Hypotheses giving polarizations of more than three standard deviations from the experimental result were rejected. On this basis the polarization measurements assign $J^\pi = \frac{5}{2}^+$ for the 2868 keV level, $\frac{9}{2}^+$ for the 4050 keV level, $\frac{7}{2}^+$ for the 4096 keV level, and $\frac{11}{2}^-$ for the 4868 keV level.

Recent shell model calculations by Wildenthal *et al* (1971) on ^{33}S have predicted positive parity states which can be compared with the experimental data, as shown in figure 1. This model has predicted a $J^\pi = \frac{5}{2}^+$ level at 2740 keV which has been

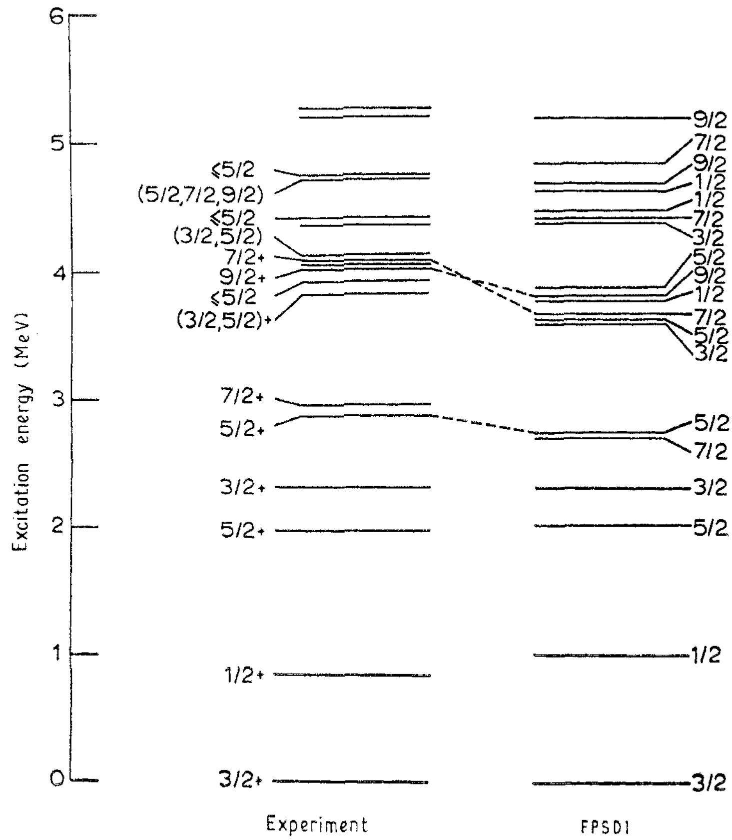

Figure 1. A comparison of the experimentally observed states in ^{33}S, whose parities are either positive or as yet undetermined, with the FPSDI shell model calculations (Wildenthal *et al* 1971). The broken lines link levels being compared in this experiment.

identified with the experimental 2868 keV level. The calculated M1 transition strength for the decay from this level is 70 mWu which is in good agreement with the experimental value of 39^{+27}_{-12} mWu. The shell model scheme also includes a $\frac{9}{2}^+$ level at

3810 keV which is near the experimental $\frac{9}{2}^+$ level at 4050 keV. Similarly the predicted $\frac{7}{2}^+$ level at 3650 keV could be assigned to the experimental 4096 keV level. The published calculations do not give electromagnetic matrix elements for these $\frac{9}{2}^+$ and $\frac{7}{2}^+$ levels.

We would like to thank Professor L L Green for his support and interest in this work, and Mr J B Reynolds for making the targets. This work was supported by the UK Science Research Council and two of us (PJN, DAV) acknowledge the receipt of SRC postgraduate studentships during the period of this work.

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