Mean lifetimes of levels in ^{32}P and ^{32}S (populated in $^{29}Si(\alpha, p)$ and $^{29}Si(\alpha, n)$ reactions)

1973 J. Phys. A: Math. Nucl. Gen. 6 705

(http://iopscience.iop.org/0301-0015/6/5/017)

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

Mean lifetimes of levels in ^{32}P and ^{32}S†

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MS received 6 September 1972

Abstract. Lifetimes of low-lying levels in ^{32}P and ^{32}S have been measured using the Doppler shift attenuation method. The levels were populated via the $^{29}Si(\alpha, p)^{32}P$ and $^{29}Si(\alpha, n)^{32}S$ reactions at α particle energies of 8·0 and 9·5 MeV. Seven new lifetimes and two new lifetime limits have been measured in ^{32}P and one new lifetime has been measured in ^{32}S. The principal decay modes of some levels have been measured.

1. Introduction

Most level lifetimes in ^{32}S below 7 MeV excitation have been measured several times using the $^{31}P(p, \gamma)$ reaction (Evans *et al* 1968, Thibaud *et al* 1969, Piluso *et al* 1969, Coetzee *et al* 1972), the $^{32}S(p, p'\gamma)$ reaction (Ollerhead *et al* 1970, Ingebretsen *et al* 1971) and the $^{32}S(\alpha, \alpha'\gamma)$ reaction (Garvey *et al* 1969, 1971). Only one paper, however, has been published on lifetimes in ^{32}P of levels higher than its first excited state (van Middelkoop and Gunsing 1970).

2. Experimental method

Levels in ^{32}P and ^{32}S were populated by the $^{29}Si(\alpha, p)^{32}P$ ($Q = -2{\cdot}455$ MeV) and the $^{29}Si(\alpha, n)^{32}S$ ($Q = -1{\cdot}528$ MeV) reactions at α particle energies of 8·0 and 9·5 MeV. Gold-backed targets of 700 and 990 $\mu g\,cm^{-2}$ of SiO_2 enriched to 95% in ^{29}Si were used at these respective energies. The density of the SiO_2 was taken as $2{\cdot}4 \pm 0{\cdot}2\ g\,cm^{-3}$ to allow for a lack of knowledge in the composition of the target. This was found to lead to a possible systematic uncertainty of ±10% in the lifetimes.

The experimental and analytical methods used in the present work were similar to those of previous publications (Alderson and Dawson 1970, Sharpey-Schafer *et al* 1971, Durell *et al* 1972). The stopping power program used (J Naser, private communication) was similar to that used in previous papers but was extended for two layer targets.

3. Results

The escape suppressed and pair escape spectra taken with a Ge(Li)–NaI(Tl) spectrometer at a bombarding energy of 9·5 MeV and an angle of 90° to the beam are shown

† This work was supported by grants from the UK Science Research Council.
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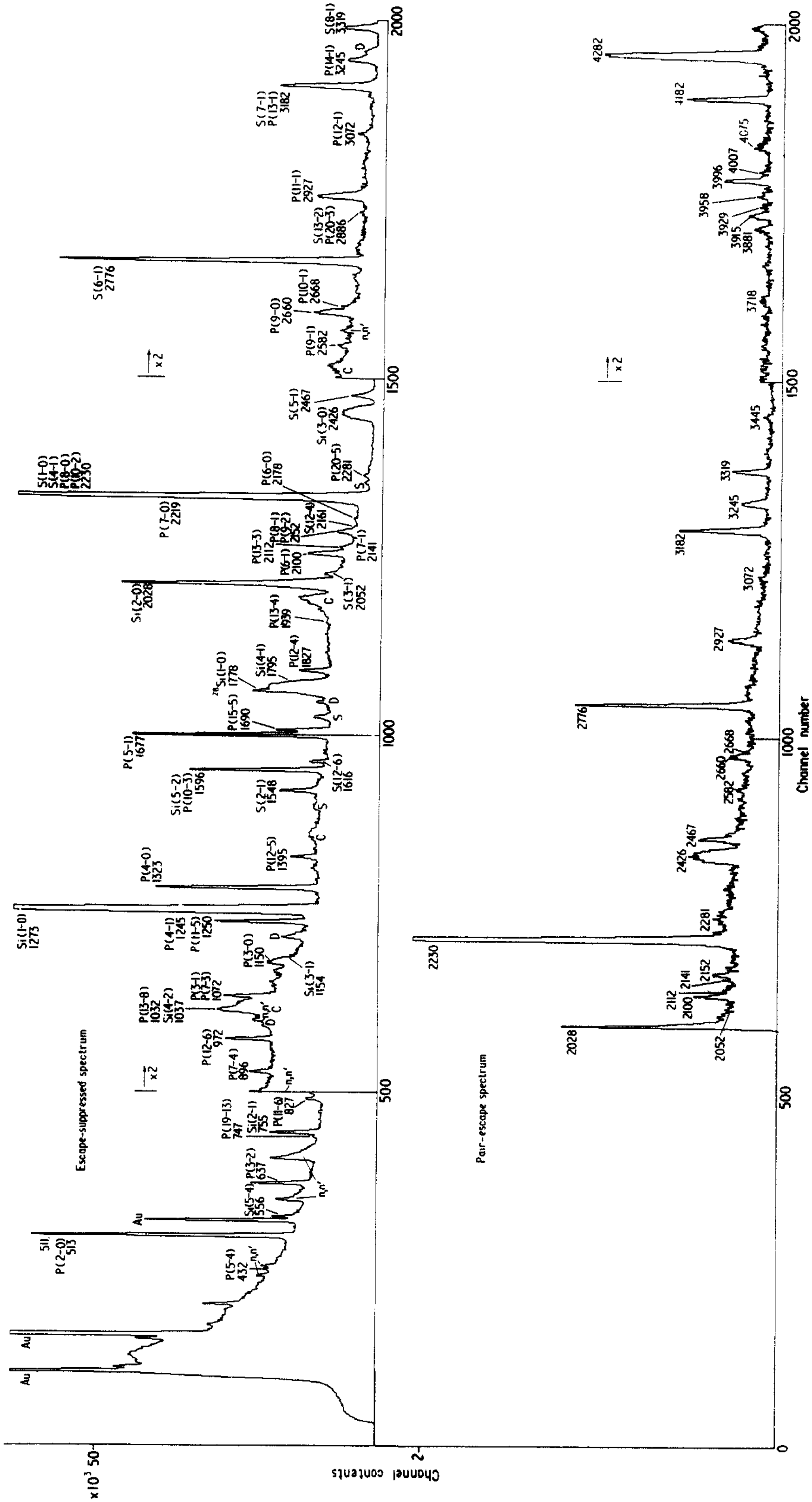
Escape-suppressed spectrum
Pair-escape spectrum
Channel number
Channel contents
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1000
1500
2000
×2

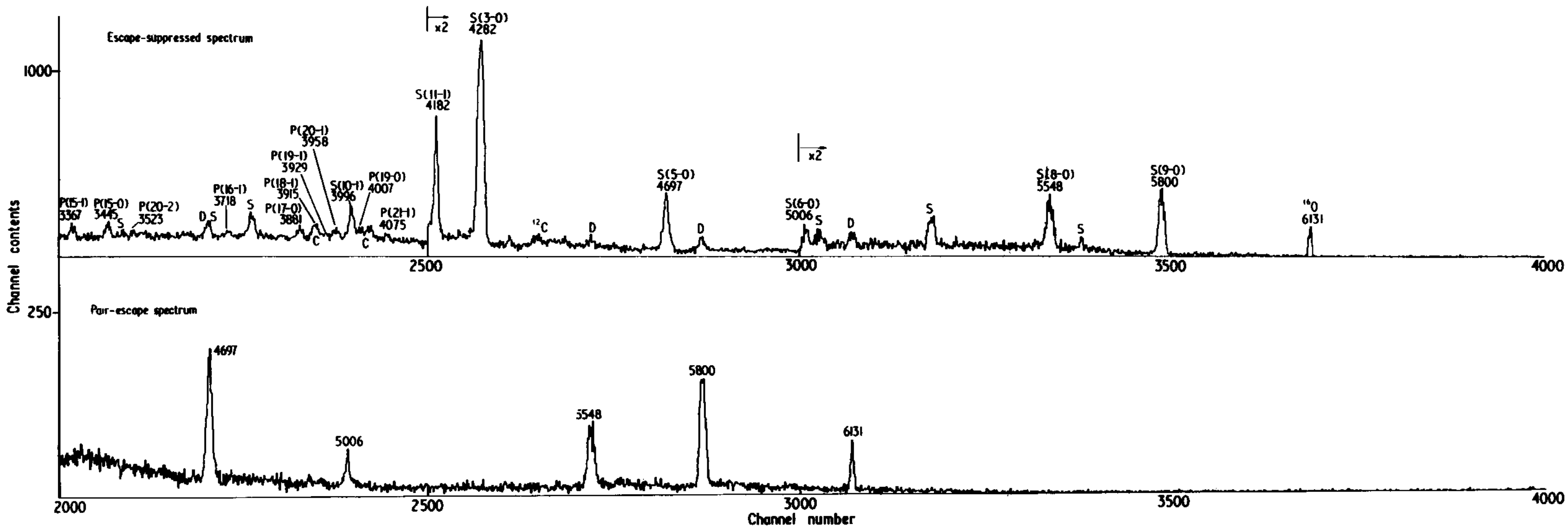

Figure 1. Escape suppressed and pair escape spectra of γ rays from the reactions $^{29}Si(\alpha, p)^{32}P$ and $^{29}Si(\alpha, n)^{32}S$, $E_\alpha = 9.5$ MeV, $\theta = 90°$. Peaks labelled C, D and S in the escape suppressed spectrum are Compton edges and double and single escape peaks.

in figure 1. These show many unresolved γ rays owing to the density of low-lying levels in ^{32}P. The decay schemes, with branching ratios, of ^{32}P and ^{32}S shown in figures 2 and 3 summarize the present and previous results.

The measured excitation energies, attenuation factors (F) and lifetimes (τ) are given in tables 1 and 2. The lifetimes in ^{32}P are compared with the lifetimes measured by van Middelkoop and Gunsing (1970).

The results for the individual nuclei are discussed separately below.

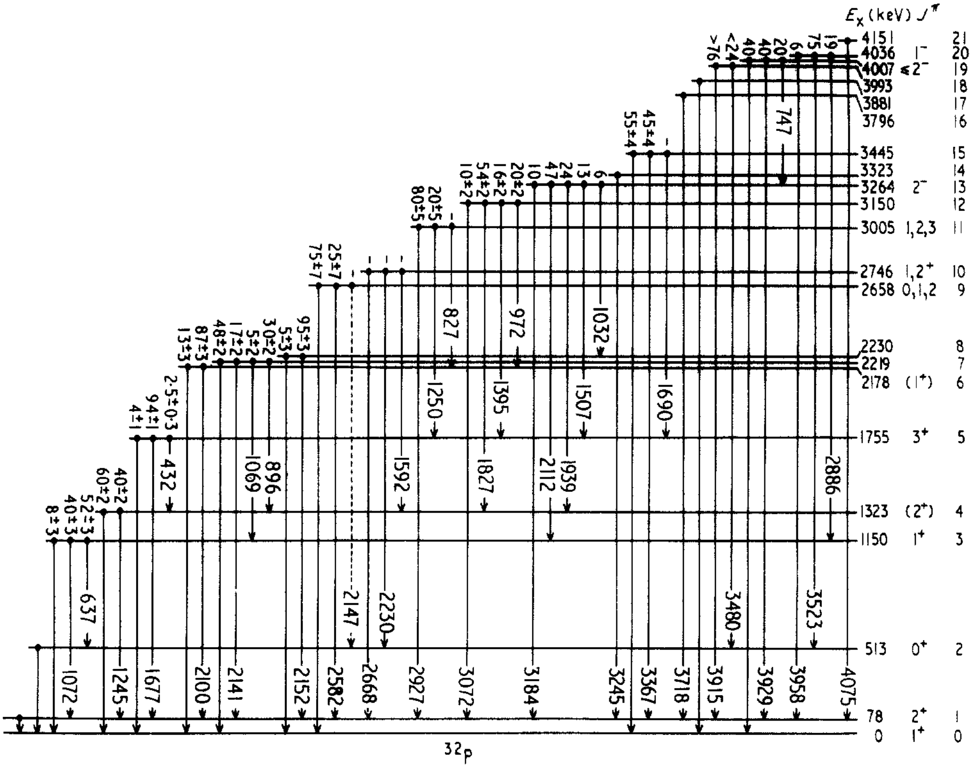

Figure 2. Decay scheme of levels in ^{32}P populated in the present work summarizing previous and the present results. Broken lines indicate uncertain assignments. Relative intensities (%) with errors are shown at the head of each transition. A dash indicates that no measurement has been made.

3.1. *The nucleus* ^{32}P

No measurements were made on γ rays from the first and second excited states of this nucleus. The energy of the former was below the lower threshold set on the electronics and the latter's ground state transition is not resolved from the 511 keV positron annihilation peak. Other levels on which no measurements could be made owing to degeneracies or to weakness of excitation were the 2230, 3264, 4007 and 4036 keV levels.

Most of the excitation energies and relative intensities measured are in agreement with previous work (Endt and van der Leun 1967, van Middelkoop and Gunsing 1970, Moss *et al* 1970, St Pierre *et al* 1971). Agreement with the lifetimes measured by van Middelkoop and Gunsing using the $^{29}Si(\alpha, p)$ reaction is reasonable.

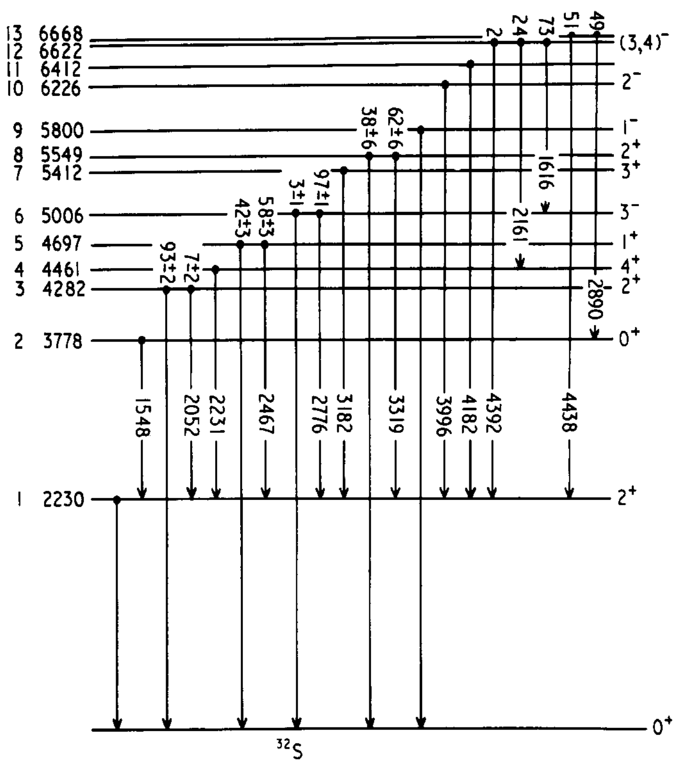

Figure 3. Decay scheme of levels in ^{32}S below 6·7 MeV excitation summarizing previous and present results. Relative intensities (%) with errors are shown at the head of each transition.

3.1.1. The 1323 keV level (4). There is a possibility of contamination of the 1245 keV (4–1) peak by the 1250 keV (11–5) γ ray observed by St Pierre *et al* (1971) as a 20% branch. This branching ratio gives a 3% and a 14% contamination of the 4–1 peak at $E_\alpha = 8{\cdot}0$ and 9·5 MeV respectively. The lifetime and relative intensity measurements for the fourth level were taken from the $E_\alpha = 8$ MeV data. The correction to the lifetime of this level for feeding by the ^{32}P(7–4) transition was small.

3.1.2. The 2746 keV level (10). The peak observed with an energy of 1596 keV could arise from the ^{32}P(10–3) and ^{29}Si(5–2) transitions. The F factor of this peak from the $E_\alpha = 8$ MeV data corresponds to a ^{32}P lifetime of 7000^{+3000}_{-1800} fs. Bailey *et al* (1972) have measured the lifetime of the fifth level in ^{29}Si to be 4200 ± 500 fs. The only other major decay from the fifth level was the 11% ^{29}Si(5–4) branch ($E_\gamma = 556$ keV) which was not observed in the present work in the $E_\alpha = 8$ MeV spectra so it was concluded that the 1596 keV peak was uncontaminated ^{32}P(10–3) at that energy.

In the present work a bump was observed on the high energy tail of the 2660 keV (^{32}P, 9–0) peak. This bump which persisted in the pair escape spectrum, was assigned to a ^{32}P(10–1) transition. St Pierre *et al* (1971) observed, in their NaI coincidence spectra for the 2·75 MeV level, a 2·66 MeV peak, but explained this as due to contamination of their 2·75 MeV proton group by the 2·66 MeV group (^{32}P, 9th level). St Pierre *et al* have also observed a 2233 keV (^{32}P, 10–2) transition.

Table 1. Excitation energies, F factors and lifetimes in ^{32}P measured in this experiment.

E_x(keV)	E_α(MeV)	$F_{average}$†	τ_m‡ (fs ± 25%)	τ_m(fs) van Middelkoop and Gunsing (1970)
1149·8 ± 0·5	8·0	0·591 ± 0·056	210 ± 44 §	270 ± 65
	9·5	0·651 ± 0·029		
1323·1 ± 0·4	8·0	0·398 ± 0·024	580 ± 55 §	380 ± 80
1754·6 ± 0·5	8·0	0·402 ± 0·024	616 ± 55	510 ± 110
2178·2 ± 0·5	8·0	0·862 ± 0·018	91 ± 14	60 ± 25
2219·0 ± 0·7	8·0	0·575 ± 0·051	287 ± 24	210 ± 50
	9·5	0·656 ± 0·033		
2658·0 ± 1·0	9·5	1·01 ± 0·07	< 40	
2746·0 ± 0·7	8·0	0·050 ± 0·015	7000^{+3000}_{-1800}	
3005·4 ± 0·5	8·0	0·860 ± 0·009	87 ± 4	
	9·5	0·881 ± 0·009		
3149·7 ± 0·5	9·5	0·480 ± 0·019	510 ± 36	
3322·6 ± 0·8	9·5	0·576 ± 0·012	360 ± 14	
3445·2 ± 0·4	9·5	0·949 ± 0·017	35 ± 14	
3795·9 ± 0·6	9·5	0·898 ± 0·053	71 ± 38	
3881·0 ± 0·5	9·5	0·964 ± 0·027	28 ± 22	
3992·5 ± 1·0	9·5	1·019 ± 0·019	< 10	
4150·6 ± 0·6	9·5	0·925 ± 0·026	52 ± 20	

† $F_{average}$ is the average F value of all the transitions observed using both full and double escape peaks.
‡ A 25% error is shown in the time scale as an indication of the uncertainty in the slowing down theory.
§ Lifetime corrected for feeding from higher levels.

Table 2. Excitation energies, F factors and lifetimes in ^{32}S measured in present work

E_x (keV)	E_α (MeV)	$F_{average}$†	τ_m‡ (fs ± 25%)
3778·4 ± 1·0	8·0	0·229 ± 0·026	1460 ± 50
	9·5	0·192 ± 0·021	
4281·5 ± 0·5	8·0	0·887 ± 0·008	64 ± 8
	9·5	0·919 ± 0·005	
4697 ± 1	8·0	0·492 ± 0·001	412 ± 25
	9·5	0·538 ± 0·010	
5006 ± 1	8·0	0·324 ± 0·007	795 ± 55
	9·5	0·336 ± 0·003§	
5412 ± 1	9·5	0·718 ± 0·018	200 ± 25‖
5548·5 ± 1·0	9·5	0·889 ± 0·005	66 ± 5
5800 ± 2	9·5	0·995 ± 0·01	< 10
6226 ± 1	9·5	0·850 ± 0·008	100 ± 8
6412 ± 2	9·5	0·946 ± 0·005¶	35 ± 6
6622 ± 2	9·5	0·208 ± 0·021	1520 ± 210

† $F_{average}$ is the average F value of all the transitions observed using both full and double escape peaks.
‡ A 25% error is shown in the time scale as an indication of the uncertainty in the slowing down theory.
§ F factor was corrected for feeding from higher levels after averaging.
‖ Estimated 4% contaminated by ^{32}P (13–1).
¶ Estimated 5% contamination of full energy peak by single escape peak of the 4697 γ ray.

3.1.3. Other levels in ^{32}P. It was not possible to measure the relative intensities of the 11–1 and 11–6 peaks in the present work, owing to the contamination of the latter by a peak due to an (n, n′) reaction.

The peak at 3482 keV can be assigned to a ^{32}P(18–2) transition or to the single escape peak of the 3996 keV (^{32}S, 10–1) γ ray. The relative intensities of full energy peaks to their single escape peaks in this energy range indicates that the peak is mostly, if not all, single escape. The evidence of the pair escape spectrum is inconclusive. An upper limit of 24 % has been placed on the relative intensity of the ^{32}P(18–2) branch.

3.2. The nucleus ^{32}S

The degeneracy of the 1–0 and 4–1 transitions precluded any measurements of the first and fourth levels. The lifetimes measured for other states provide a useful check on previous measurements due to the higher recoil velocity and different stopping material used.

3.2.1. The 4697 keV level (5). An unidentified contaminant was observed in the 2467 keV (5–1) peak in the E_α = 8·0 and 9·5 MeV data. This contaminant which caused significant disagreement between the F factors for the 5–0 and 5–1 transitions (F(5–1) = 0·60 ± 0·06 and 0·74 ± 0·07 at E_α = 8·0 and 9·5 MeV respectively—cf table 2) had an energy of about 2470 keV and led to a relative intensity of 68 ± 3 % for the 5–1 branch. Previous measurements of this relative intensity are 58 ± 3 % (Poletti and Grace 1966), 56 % (Piluso *et al* 1969) and 61 ± 3 % (Coetzee *et al* 1972).

3.2.2. The 5412 keV level (7). The 3182 keV peak contains contributions from both the ^{32}S(7–1) and ^{32}P(13–1) γ rays. However, the 13th level of ^{32}P was not strongly excited in this experiment. Using the relative intensities quoted by Endt and van der Leun (1967) together with the intensity of the 1939 keV (^{32}P, 13–4) peak, the amount of ^{32}P contamination in the 3182 keV peak was found to be approximately 4 % which will have a negligible effect on the lifetime measurement.

3.2.3. The 6412 keV level (11). A lifetime of 35 ± 11 fs, measured for level 11, was obtained from the 4182 keV (11–1) peak which was weakly (5 %) contaminated by the single escape of the 4697 keV peak.

3.2.4. The 6622 keV level (12). The lifetime measured for this level (1520 ± 210 fs) disagrees with the values of 370 ± 80 fs and 420 ± 100 fs obtained by Piluso *et al* (1969) and Coetzee *et al* (1972) who used the ^{31}P(p, γ) reaction. However Thibaud *et al* (1969), using the same reaction, set a lower limit of 1000 fs on this lifetime.

4. Conclusion

We have measured seven new lifetimes and two new lifetime limits of excited states in ^{32}P and one new lifetime (of the 6412 keV level) in ^{32}S. Our results for ^{32}S are in good agreement with the work of Ollerhead *et al* (1970), Ingebretsen *et al* (1971) and Garvey *et al* (1969, 1971). Agreement is less satisfactory with the measurements of Evans *et al* (1968), Thibaud *et al* (1969) and Piluso *et al* (1969) who used the reaction ^{31}P(p, γ)^{32}S.

Recent shell model calculations (Glaudemans *et al* 1971, Wildenthal *et al* 1971) have had reasonable success in predicting the level schemes of the $A = 32$ nuclei. An extension of these calculations to the higher levels of ^{32}P would be of interest. Before any valid comparisons with the present data can be made, however, more mixing ratio measurements are necessary in this nucleus.

Acknowledgments

We would like to thank Mr J B Reynolds for making the targets used in this work. Three of us (DCB, PEC and DAV) acknowledge the receipt of SRC postgraduate studentships for part or all of the duration of this work and PEC acknowledges support from the Ministry of Social Security.

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