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INVESTIGATION OF THE $^{32}S(n, \gamma)^{33}S$ REACTION

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Abstract: The γ radiation following thermal neutron capture in ^{32}S was investigated with scintillation spectrometers. From γ-γ coincidence and angular correlation measurements the following spin assignments in ^{33}S were derived: $J(1.97) \geqq \frac{3}{2}$, $J(2.31) = \frac{3}{2}$, $J(4.21) = \frac{3}{2}$, $J(4.92) = (\frac{1}{2}, \frac{3}{2})$, $J(5.71) = \frac{1}{2}$, $J(5.89) = \frac{3}{2}$, $J(7.19) = \frac{3}{2}$ and $J(7.41) = (\frac{1}{2}, \frac{3}{2})$.

New transitions in the γ-ray decay were found, a few of which are of M1 character competing favourably with E1 radiation.

E | NUCLEAR REACTIONS ^{32}S (n, γ), E = thermal; measured E_γ, I_γ, $\gamma\gamma$-coin., $\gamma\gamma(\theta)$. ^{33}S deduced levels J, branching. Natural target.

1. Introduction

The γ radiation following thermal neutron capture in ^{32}S was investigated with a magnetic Compton spectrometer by Groshev *et al.* [1]), with a magnetic pair spectrometer by Kinsey *et al.* [2]) and by Bartholomew and Higgs [3]), and with a two-crystal pair spectrometer by Braid [4]). Circular polarization of γ radiation after capture of polarized neutrons was measured by Trumpy [5]) and Vervier [6]) yielding E1 character for the dominant C → 3.22 MeV transition and $J^\pi(3.22) = \frac{3}{2}^-$. Recently Abrahams *et al.* [7]) reported circular polarization measurements yielding $J^\pi(5.71) = \frac{1}{2}^-$ and $J^\pi(4.21) = \frac{3}{2}^-$. The $J(3.22) = \frac{3}{2}$ assignment was confirmed by Manning and Bartholomew [8]) who measured γ-γ angular correlations with scintillation spectrometers.

The level structure of ^{33}S and the l_n values of many levels are known from the $^{32}S(d, p)^{33}S$ reaction [9]). Spin dependence of the proton angular distribution for the $l_n = 2$ groups in this reaction is reported by Schiffer *et al.* [10]). From their measurements they suggest $J^\pi(2.31) = \frac{3}{2}^+$. Quite recently, Becker *et al.* [11]) measured spins of a few low-lying states, using the $^{32}S(d, p\gamma)^{33}S$ reaction, by detecting the protons at 180° and measuring γ-ray angular distributions. They found $J(0.84) = \frac{1}{2}$, $J(1.97) =$ $= \frac{5}{2}$, $J(2.31) = \frac{3}{2}$, $J(2.937) = \frac{7}{2}$ and $J(3.22) = \frac{3}{2}$.

A compilation of information about ^{33}S, obtained until 1962, is given by Endt and Van der Leun [9]).

The present work is an extension of work reported in ref. [12]) where γ-γ coincidence and angular correlations were measured with scintillation counters, especially on a 7.20–1.44 MeV γ-ray cascade to search for a shell-model predicted $\frac{5}{2}^+$ level [13]) at about 1.4 MeV. The primary intention now was to investigate once more the 7.20–1.44 MeV γ-ray cascade, since the former results were not conclusive. Moreover, it was obvious from these preliminary measurements that a better decay scheme could be constructed.

2. Experimental Arrangement

The γ-γ angular correlation set-up at the Dutch High Flux Reactor in Petten was described earlier [12]).

The target is placed in a horizontal radial beam of this reactor. The present experiments were carried out with an increased flux compared to those reported in ref. [12]). The neutron filter, consisting of quartz and bismuth single crystals, was cooled to 77° K by liquid nitrogen. The initial increase in the beam flux due to cooling is a factor 3.8. However, unfortunately, at the same time an in-pile experiment was installed in the reactor core, reducing the flux by nearly a factor of two. The final increase in beam flux therefore is only a factor of two, the flux now being 8×10^6 $cm^{-2} \cdot s^{-1}$. The teflon target holder had an inner diameter and length of 1 and 2 cm, respectively. It was filled with 2g of sulphur powder.

Two gain-stabilized 12.7 cm × 12.7 cm NaI(Tl) spectrometers with their axes perpendicular to the neutron beam detect the neutron capture γ radiation. One of the spectrometers can be rotated in a vertical plane around the beam direction. The detector solid angles are 0.13 and 0.31 sr for the movable and stationary detector, respectively. The detectors are coupled to a fast-slow coincidence system having a resolving time of $2\tau = 30$ ns. Mostly two coincidence measurements with different energy gates are performed simultaneously by using the routing system of a 400-channel analyser.

Angular correlation measurements ran over a chosen set of angles, either $\theta = 180°$, 150°, 135°, 120° and 90° or $\theta = 180°$, 135° and 90°, automatically. At each angle a 1h measurement is performed, corrected for dead time, and a cycle of five or three angles is repeated many times. The data compiled at every angle, the neutron flux, the total number of coincidences and the coincidence spectra, are punched on paper tape.

3. Analysis of the Results

In order to construct a decay scheme, a single spectrum and fourteen coincidence spectra were taken, the latter with gates in the 2.3–5.6 MeV region.

The spectra were computer analysed. The computer calculates the pulse-height distribution for every given γ-ray energy from a series of numerical distributions at 3, 4, 5 . . . 12 MeV. For energies below 3 MeV this interpolation is performed between distributions given at 0.4, 0.8 . . . 3.2 MeV. The pulse-height distributions are then fitted by a least-squares method to the experimental spectrum.

This method requires that the γ-ray energies are known beforehand. Since this is generally not the fact, the first coincidence spectra, containing most of the γ rays, i.e. coincident with a low-energy gate, were analysed with a "trial and error" method:

the energies of clear peaks in the spectra are given to the computer, and where definite differences between the experimental and calculated spectra occur new γ rays are introduced. Also γ rays observed by preceding high-resolution work [9]) were inserted. Once knowing the energies, it is simple to analyse the other spectra, sometimes introducing new γ rays which come in more prominently. Then a tentative decay scheme was constructed from these fourteen coincidence measurements.

Because the level energies are known from the (d, p) work with much higher accuracy than the γ-ray energies, the latter were corrected into "true" values. Generally, the correction was not more than 0.02 MeV. The single spectrum was analysed, finally, with the "best" energies, generally being the "true" values for the weak lines and the observed values for the strong lines.

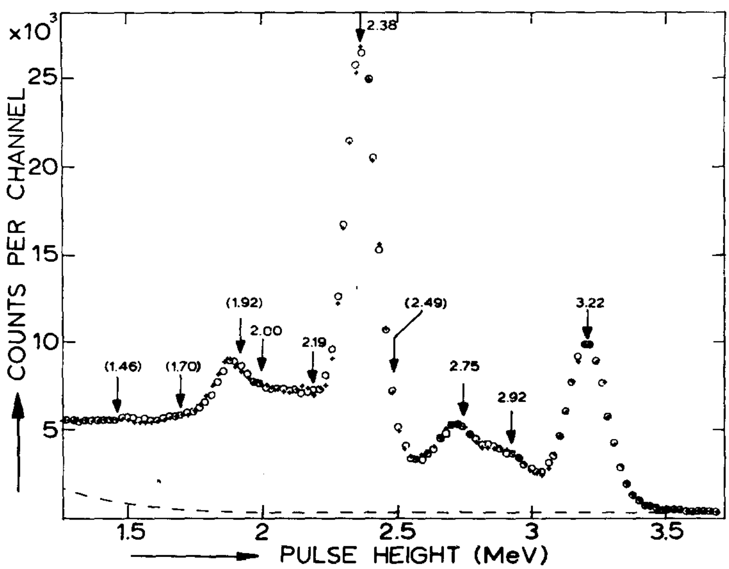

Fig. 1. Computer analysis of the spectrum coincident with a 5.26–5.59 MeV gate. The experimental spectrum is given by circles, the calculated spectrum by crosses. The dotted line indicates the residue.

The last step to complete the decay scheme was the calculation of each coincidence spectrum, using the tentative decay scheme. For this purpose the contribution of every γ ray, known from the single spectrum, to the "self-gated" spectrum was estimated, after the reduction of the intensities of all γ rays to unit counting time and flux. Again through an iterative method the decay scheme was modified until a good fit for nearly all coincidence spectra was obtained.

There appeared to be a residue in the spectra, mainly at low energies, which could not be explained by introducing new γ rays. For this reason, in the analysis, a residue function R is also given to the computer:

$$R = a_0 + a_1 e^{-2E} + a_2 e^{-3E} + a_3 e^{-4E},$$

in which E is the energy in MeV and a_0 through a_3 are variable parameters. This residue should account for systematic errors in the low-energy Compton tails of high-energy γ rays, for the presence of a continuum of weak low-energy γ rays, for pile-up, and for background, partly due to activation of the NaI crystals. The residue is only important below 2 MeV.

The coincidence spectra are the sum of spectra measured at θ = 180°, 135° and 90°. It might thus be expected that the intensities found are not very much influenced by angular correlation effects, although a small systematic error must be expected.

In fig. 1 an example of a computer analysis is shown on the spectrum coincident with a 5.26–5.59 MeV gate. The γ-ray energies used in the analysis are given. The

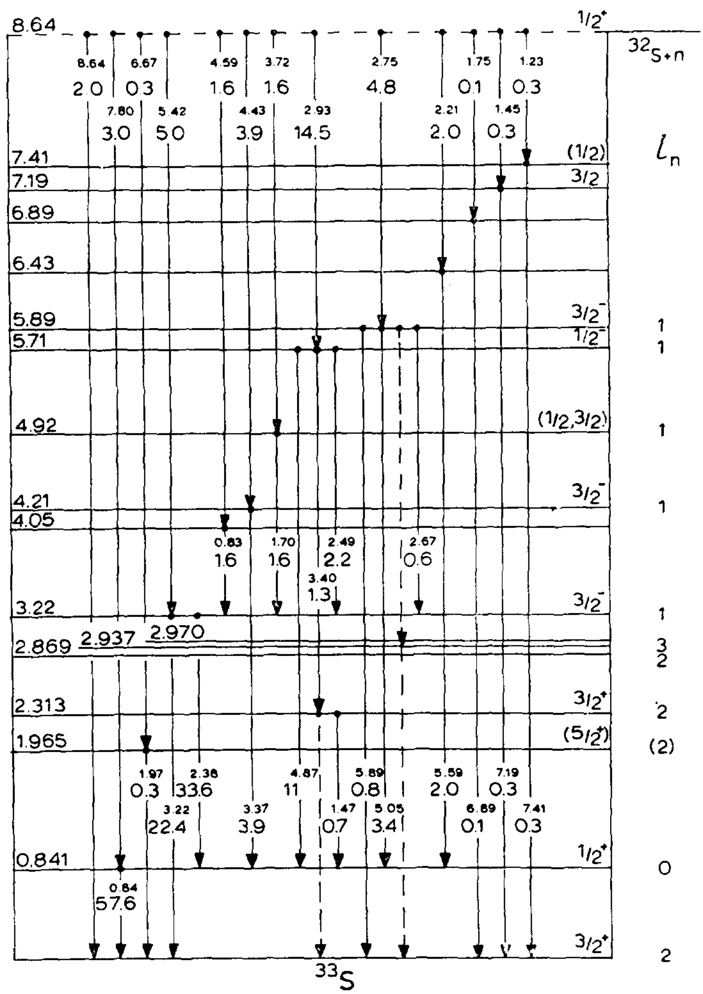

Fig. 2. Decay scheme of ^{33}S. The excitation energies and l_n values are from ref. [9]). The intensities are in number of γ rays per 100 captures.

γ rays indicated in brackets were found with intensity equal to zero within the error. The residue is shown as a dotted line.

4. Experimental Results

The capture cross section [14]) of natural sulphur is 0.52 ± 0.02 b. Abundances and cross sections of the four isotopes indicate that most of the capture occurs in ^{32}S. The next largest contribution (2 %) is from the $^{34}S(n, \gamma)^{35}S$ reaction [9]). The neutron binding energies for ^{33}S and ^{35}S are 8.64 and 6.98 MeV, respectively [9]).

4.1. DECAY SCHEME

The decay scheme, partly proposed from and partly confirmed by the present experiment, is shown in fig. 2. Some two-step cascades are taken from ref. [12]). The other transitions are fitted in the level scheme using the method described in sect. 3.

Table 1 lists the γ rays observed in the fourteen coincidence spectra and the single spectrum, with their intensities determined as described in sect. 3. The γ-ray intensities are calibrated on an assumed 50 % intensity of the 5.42 MeV γ ray, estimated from refs. [1,3]). The error in this value is about ± 5 %. As is seen from the decay scheme and from table 1, 84 ± 12 % of the capturing state γ-ray decay is found. This means that 16 ± 12 % is still unknown. The residue observed in the single spectrum can account for this missing amount.

A single spectrum, corrected for background, is shown in fig. 3. The residue and the pulse-height distribution for each γ ray, calculated in the analysis of the spectrum, are indicated by dotted lines.

In general the decay scheme in fig. 2 is consistent with that given in ref. [1]). New transitions or cascades are the following.

(i) *The* 4.05 → 3.22 MeV *transition.* The existence of this cascade follows from figs. 4 and 5 where a 4.59 MeV γ ray, the C → 4.05 MeV transition, is found in coincidence with the 3.22 and 2.38 MeV γ rays, which are the 3.22 → 0 and 3.22 → 0.84 MeV transitions, repectively.

(ii) *The* C → 4.92 → 3.22 MeV *cascade.* From figs. 4 and 6 it follows that the 3.72, 1.70 and 3.22 MeV γ rays form one cascade, see also fig. 7. This γ-ray cascade càn only proceed through the 4.92 and 3.22 MeV levels since no "mirrors" are possible. In addition, from fig. 5 it is seen that the 1.70 and 3.72 MeV γ rays are also coincident with the 2.38 MeV γ ray, as must be expected from the decay of the $E_x = 3.22$ MeV state.

(iii) *The* 5.71 → 2.31 → 0.84 MeV *cascade.* Fig. 7 shows that the 3.40 and 1.47 MeV γ rays are coincident with the 2.93 MeV γ ray. From an additional coincidence measurement with $E_\gamma = 3.40$ MeV it is proved that the 2.93, 3.40 and 1.47 MeV γ rays form one cascade. This cascade can only proceed through the 5.71, 2.31 and 0.84 MeV levels.

TABLE 1

Gamma rays observed in the $^{32}S(n, \gamma)^{33}S$ reaction

E_γ [a]) (MeV)	Intensity [b]) (number of γ rays per 100 captures)	Probable transition in ^{33}S
8.64 [c])	2.0±0.5	C → 0
7.80	3.0±0.6	C → 0.84
7.41 [d])	0.3±0.1 [d])	7.41 → 0
7.19 [d])	0.3±0.1 [d])	7.19 → 0
6.89 [d])	0.1±0.05 [d])	6.89 → 0
6.67 [d])	0.3±0.1 [d])	C → 1.97
5.89 [c])	0.8±0.2	5.89 → 0
5.59	2.0±0.5	6.43 → 0.84
5.42 [c])	50	C → 3.22
5.05 [c])	3.4±0.5	5.89 → 0.84
4.87 [c])	11.0±1.0	5.71 → 0.84
4.59 [c])	1.6±0.4	C → 4.05
4.43 [c])	3.9±0.5	C → 4.21
3.72 [c])	1.6±0.4	C → 4.92
3.40 [c])	1.3±0.3	5.71 → 2.31
3.37 [c])	3.9±0.5	4.21 → 0.84
3.22 [c])	22.4±2.0	3.22 → 0
2.93 [c])	14.5±1.5	C → 5.71
2.75 [c])	4.8±0.7	C → 5.89
2.67	0.6±0.3	5.89 → 3.22
2.49 [c])	2.2±0.5	5.71 → 3.22
2.38 [c])	33.6±3.0	3.22 → 0.84
(2.31)	(0.6±0.3)	(2.31 → 0)
2.21 [c])	2.0±0.5	C → 6.43
1.97 [d])	0.3±0.1 [d])	1.97 → 0
1.75 [d])	0.1±0.05 [d])	C → 6.89
1.70 [c])	1.6±0.4	4.92 → 3.22
1.47 [c])	0.7±0.2	2.31 → 0.84
1.45 [d])	0.3±0.1 [d])	C → 7.19
1.23 [d])	0.3±0.1 [d])	C → 7.41
0.84 [c])	57.6±6.0	0.84 → 0
0.83	1.6±0.4	4.05 → 3.22

[a]) Energies are interpreted values.

[b]) The intensities are normalized to the 50 % intensity of the 5.42 MeV line as estimated from refs. [1,3]). A 10% error might exist in this value; this error is not included in the errors given for the other intensities.

[c]) These γ rays are also observed in the single spectrum.

[d]) From ref. [12]).

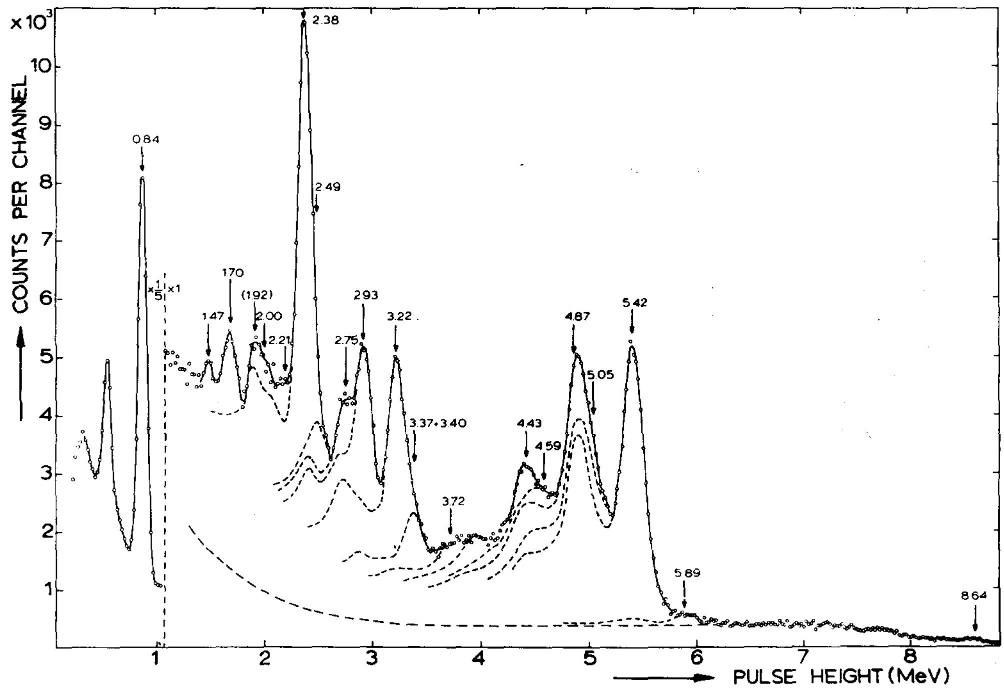

Fig. 3. Single spectrum of the $^{32}S(n, \gamma)^{33}S$ reaction, corrected for background. Detector solid angle 0.13 sr, counting time 3 min.

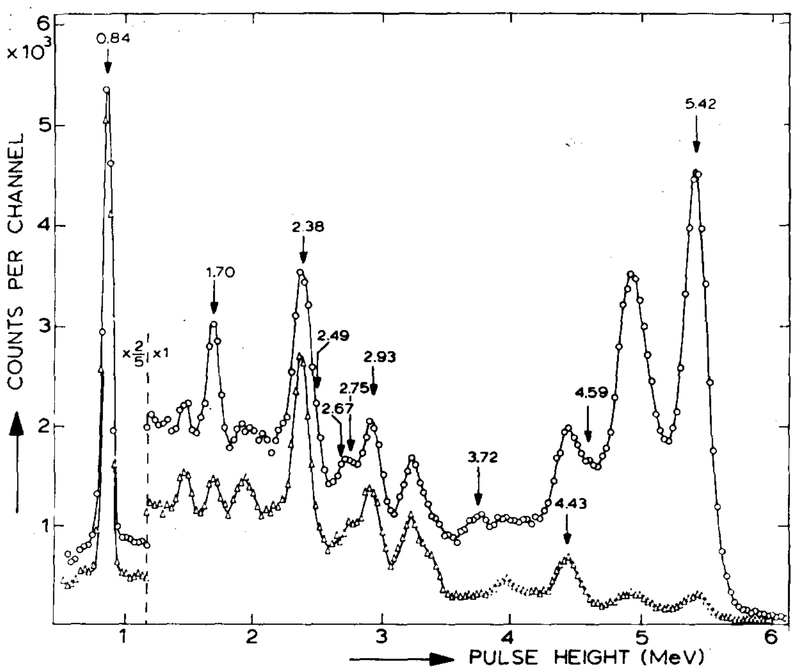

Fig. 4. Spectrum coincident with 3.16–3.31 MeV channel (circles) and spectrum coincident with 3.45–3.60 MeV channel (triangles).

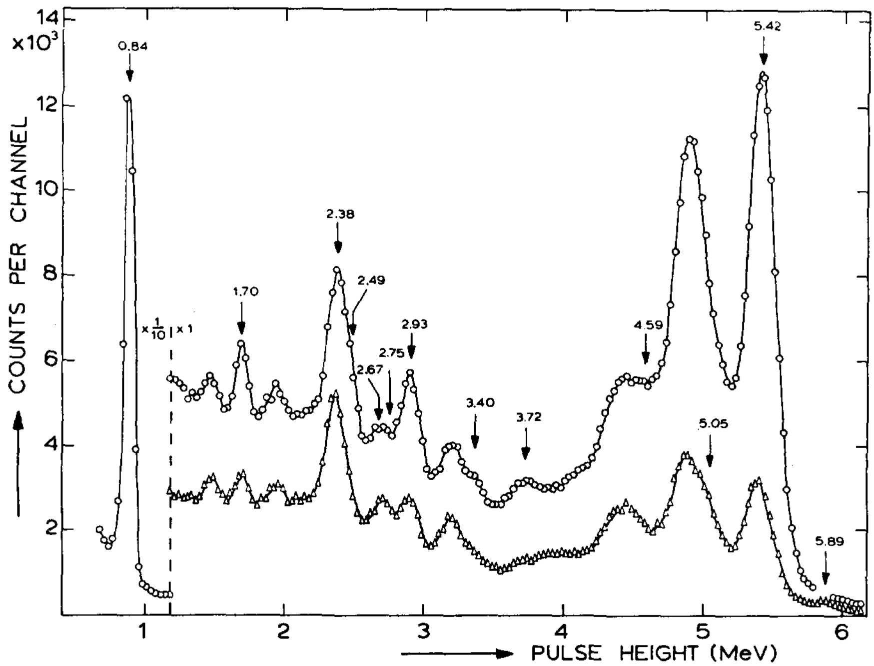

Fig. 5. Spectrum coincident with 2.28–2.50 MeV channel (circles) and spectrum coincident with 2.60–2.82 MeV channel (triangles).

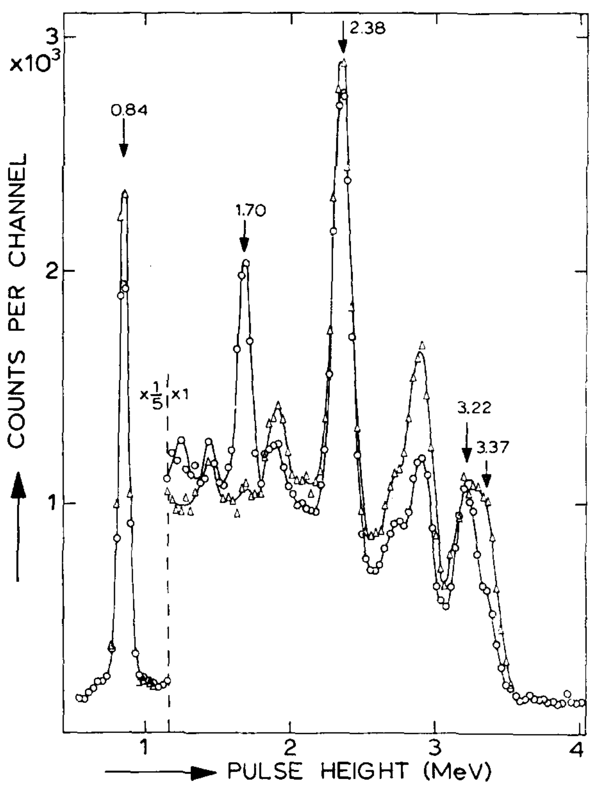

Fig. 6. Spectrum coincident with 3.63–3.82 MeV channel (circles) and spectrum coincident with 3.89–4.08 MeV channel (triangles).

(iv) *The* 5.71 → 3.22 MeV *transition.* A 2.49 MeV γ ray is found in figs. 4, 5 and 7. A spectrum coincident with the 2.49 MeV γ ray shows 2.38, 2.93 and 3.22 MeV γ rays, see fig. 8. From these observations and from an angular correlation measurement (see subsect. 4.2.) the existence of the 5.71 → 3.22 MeV transition is proved.

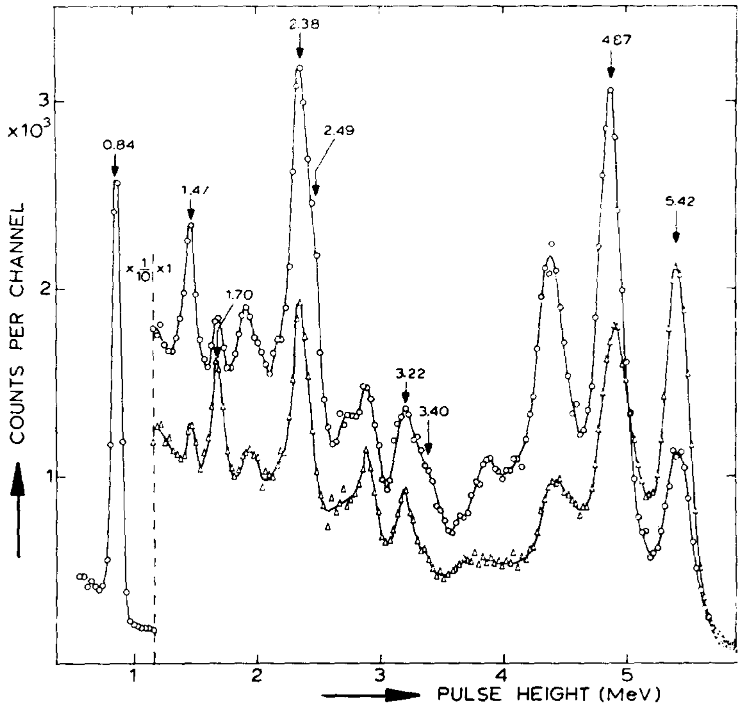

Fig. 7. Spectrum coincident with 2.89–3.00 MeV channel (circles) and spectrum coincident with 3.11–3.22 MeV channel (triangles).

(v) *The* 5.89 → 3.22 MeV *transition.* In figs. 4 and 5, γ rays of 2.67 and 2.75 MeV are found which are coincident with the 3.22 and 2.38 MeV γ rays. The 2.67 MeV γ ray is also seen in fig. 5 (triangles), coincident with $E_\gamma = 2.75$ MeV. It is reasonable therefore to interpret the 2.67 MeV γ ray as the 5.89 → 3.22 MeV transition, although a C → 5.97 MeV transition combined with a 5.97 → 3.22 MeV transition would also explain these observations.

(vi) *The* C → 6.43 → 0.84 MeV *cascade.* Its existence follows from fig. 1 showing a 2.19 MeV γ ray. Also in a sum-coincidence measurement, with a 7.69–7.91 MeV gate, a 2.19 ± 0.03–5.60 ± 0.05 MeV γ-ray cascade is detected.

(vii) *The* 2.31 → 0 MeV *transition.* In the spectrum coincident with $E_\gamma \approx 2.38$ MeV, see fig. 5, the 2.93 and 3.40 MeV γ rays in the C → 5.71 → 2.31 MeV cascade, are found to be stronger than expected on the basis of the decay scheme. This can be explained by assuming that a 2.31 → 0 MeV transition exists. Moreover the population of the 2.31 MeV level by the 3.40 MeV γ ray is found to be stronger than the depopulation of this level by the 1.47 MeV γ ray, from the spectrum coincident with E_γ = 2.93 MeV, see fig. 7.

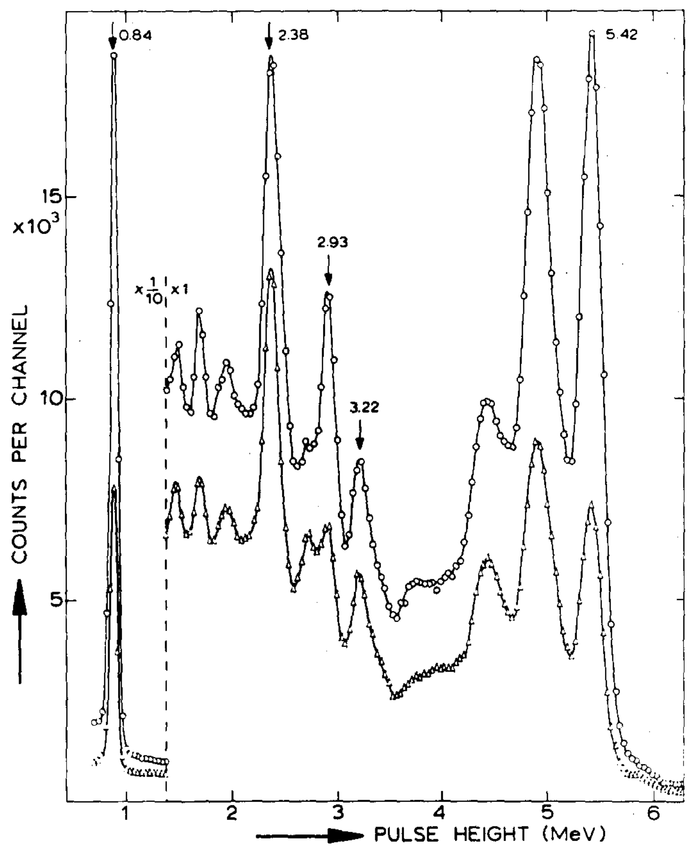

Fig. 8. Spectrum coincident with 2.41–2.57 MeV channel (circles) and spectrum coincident wit 2.59–2.74 MeV channel (triangles).

(viii) *The two-step cascades between the capturing state and the ground state througl the* 1.97, 6.89, 7.19 and 7.41 MeV *levels*. The first two are already given in ref. [12]) The 1.44–7.20 MeV γ-ray cascade [12]) is assumed to proceed through the E_x = 7.1[illegible] MeV state [9]), see subsect. 4.2. The 1.20±0.02–7.45±0.04 MeV γ-ray cascade [12]) i now assumed to proceed through the E_x = 7.41 MeV state [9]) since the low-energ γ ray has an energy of 1.22±0.01 MeV from this work.

(ix) *The* 5.89 → 2.9 → 0 MeV *cascade*. From some coincidence measurements i indirectly follows that this cascade may exist.

From these coincidence measurements the existence of known [1]) cascades is confirmed. The intensities given are, but for the absolute calibration, from this work.

4.2. SPINS AND PARITIES

The ^{33}S ground state [9]) has spin and parity $\frac{3}{2}^+$. The capturing-state spin and parity are $\frac{1}{2}^+$ because ^{32}S has $J^\pi = 0^+$ (ref. [9])).

The results of the angular correlation measurements are listed in table 2. Measurements 1 and 7–9 were five-angle runs, $\theta = 180°, 150°, 135°, 120°$ and $90°$, the remaining ran over three angles, $\theta = 180°, 135°$ and $90°$. The first measurement served to test the equipment. The cascade ought to show an isotropic correlation since $J(0.84) = \frac{1}{2}$ (ref. [9])).

TABLE 2

Angular correlation coefficients A_2 and A_4 in the expression $W(\theta) \propto 1 + A_2P_2(\cos\theta) + A_4P_4(\cos\theta)$, corrected for solid angle

	Cascade (MeV)	A_2^{exp}	A_4^{exp}	A_2^{theor} a) (J = spin of intermediate level)
1.	C → 0.84 → 0 b)	0.005±0.007	0.012±0.009	
2.	C → 4.21 → 0.84 c)	0.274±0.028		0 if $J = \frac{1}{2}$; 0.25 if $J = \frac{3}{2}$ (rows 2–5)
3.	C → 5.71 → 0.84 c)	0.007±0.018		
4.	C → 5.89 → 0.84 c)	0.20 ±0.05		
5.	5.71 → 3.22 → 0.84 d)	0.38 ±0.10		
6.	C → 5.89 → 0 c)	−0.25 ±0.05		0 if $J = \frac{1}{2}$; −0.20 if $J = \frac{3}{2}$ (rows 6–11)
7.	C → 7.19 → 0 e)	−0.175±0.027	0.032±0.037	
8.	C → 7.41 → 0 e)	−0.013±0.018	0.025±0.024	
9.	C → 1.97 → 0 f)	−0.21 ±0.08	−0.13±0.11	
10.	C → 4.92 → 3.22 g)	0.011±0.034		
11.	C → 5.71 → 3.22 g)	−0.05 ±0.08		

a) Pure dipole radiation assumed.

b) Test measurement, $J(0.84) = \frac{1}{2}$ (ref. [9])).

c) The initial and final state have even parity, the intermediate state has odd parity. Both γ rays are assumed to be pure E1.

d) The initial and intermediate state have odd parity, the final state has even parity. The first transition can be of mixed M1/E2 character.

e) The initial and final state have even parity, the parity of the intermediate state is unknown.

f) The initial and final state have even parity, the intermediate state probably has even parity. Both transitions can be of mixed M1/E2 character.

g) The initial state has even parity, the intermediate and final state have odd parity. The second transition can be of mixed M1/E2 character.

From measurements 2–4 and 6 the following unique assignments can be made: $J(4.21) = \frac{3}{2}, J(5.71) = \frac{1}{2}$ and $J(5.89) = \frac{3}{2}$. From the (d, p) reaction it is known[9]) that these states all have $J^\pi = (\frac{1}{2}, \frac{3}{2})^-$, because $l_n = 1$. Thus from $A_2 \neq 0$ it immediately follows that $J = \frac{3}{2}$. In the C → 5.71 → 0.84 MeV cascade both γ rays are assumed to have E1 character.

Measurement 7 on the 7.20 and 1.44 MeV γ rays [12]), shows coefficients in agreement with a $\frac{1}{2}(1)\frac{3}{2}(1)\frac{5}{2}$ cascade. It should be noted first that these correlation coefficients disagree with those given in ref. [12]). The reason for the deviation, a factor of two in A_2, is not quite clear. Possibly an unobserved gain shift in one of the detector channels in the older experiment is responsible for this difference. In the present experiment, consisting of two runs of 10 d, the gate position relative to the spectrum is checked afterwards by computing the integral of every measured coincidence spectrum. In ref. [12]) it was shown that a shell-model predicted $\frac{5}{2}^+$ level at 1.4 MeV as well

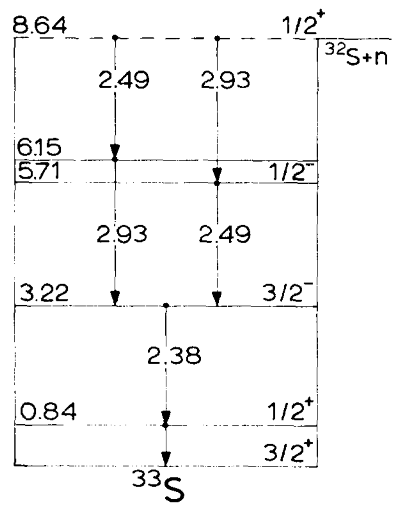

Fig. 9. Partial decay scheme of ^{33}S, illustrating the possible assignments for the 2.93–2.49 MeV γ-ray cascade.

as the E_x = 7.19 MeV level could be the intermediate state in this cascade. Since it is known that the E_x = 1.97 MeV state has [11]) $J = \frac{5}{2}$, and that the parity probably is even [9]), it is reasonable to assume that this level is the $\frac{5}{2}^+$ level predicted at 1.4 MeV. The second $\frac{5}{2}^+$ level from these shell-model calculations lies at 3.7 MeV. For that reason the 7.20–1.44 MeV γ-ray cascade is assumed to proceed through the E_x = 7.19 MeV level. From measurement 7, table 2, it follows that $J(7.19) = \frac{3}{2}$. A $J = \frac{5}{2}$ assignment is very unlikely since this requires a very strong quadrupole primary transition.

Measurement 8 indicates that $J(7.41) = \frac{1}{2}$. A $J = \frac{3}{2}$ assignment, however, cannot be excluded, since a small quadrupole admixture in one of the γ rays is sufficient to explain the measured isotropy.

The 14 d run on the C → 1.97 → 0 MeV cascade (measurement 9) was insufficient to definitely assign a spin to the E_x = 1.97 MeV state. It only can be concluded with certainty that $J(1.97) \geqq \frac{3}{2}$.

From the (d, p) work it is known [9]) that the E_x = 4.92, E_x = 4.94 MeV doublet has $l_n = 1+3$ or 4. Since the 4.92 MeV level is fed from the capturing state it is assumed that $l_n(4.92) = 1$; the other possibilities require a M2 or M3 transition as a primary. Measurement 10 indicates that $J(4.92) = \frac{1}{2}$. However, a $J = \frac{3}{2}$ assignment cannot be excluded since the 1.70 MeV γ ray can be of mixed M1/E2 character.

From the coincidence measurements reported in subsect. 4.1, a 2.93–2.49 MeV γ-ray cascade is found between the capturing state and the 3.22 MeV level. This cascade either proceeds through the 6.15 MeV level or through the 5.71 MeV level, see fig. 9. Measurement 5 in table 2 shows that the angular correlation of the 2.49 and 2.38 MeV γ rays is strongly anisotropic, while from measurement 11 it follows that the angular correlation of the 2.49 and 2.93 MeV γ rays is isotropic within the error. Therefore †) the 2.93–2.49 MeV γ-ray cascade must be assumed to proceed through the $E_x = 5.71$ MeV state. It is also seen that the measured correlation coefficients agree with those expected from the spins involved, assuming pure dipole radiation.

Finally, from the decay scheme (see subsect. 4.1.), from $J^\pi(5.71) = \frac{1}{2}^-$ and from $l_n(2.31) = 2$ (ref. [9]) it follows that $J^\pi = \frac{3}{2}^+$. The other possibility, $J^\pi(2.31) = \frac{5}{2}^+$, requires a 5.71 → 2.31 MeV M2 transition with a strength of about 30 Weisskopf units if the strength of the 5.71 → 0.84 MeV E1 transition is chosen as 2×10^{-3} Weisskopf units [14]).

5. Discussion

All γ rays with $E_\gamma \geqq 1.97$ MeV, found in this work were also observed by Groshev *et al.* [1]), except for the 6.89 and 5.59 MeV γ rays, while in the present experiment no 3.10 MeV γ ray [1]) was found. The γ-ray energies in the $E_\gamma = 2.00$–3.27 MeV region, reported by Groshev *et al.* [1]), are too high by about 0.04 MeV.

The spins of the 5.71 and 4.21 MeV levels, $J = \frac{1}{2}$, and $J = \frac{3}{2}$, respectively, confirm recent results of Abrahams *et al.* [7]). The $J(2.31) = \frac{3}{2}$ assignment is consistent with a shell-model prediction [13]) (where the predicted energy is too high by about 0.5 MeV) and with the results of Schiffer *et al.* [10]) and Becker *et al.* [11]) who studied the (d, p) and (d, pγ) processes, respectively. The $J(1.97) \geqq \frac{3}{2}$ assignments agrees with that given by Van der Leun and Endt [15]) and with the $J(1.97) = \frac{5}{2}$ assignment by Becker *et al.* [11]). If the $E_x = 1.97$ MeV state indeed is the $\frac{5}{2}^+$ level predicted by shell-model calculations [13]) at 1.4 MeV, the predicted energy is too low by about 0.6 MeV.

From the decay scheme, see fig. 2, it follows that the 4.92 → 3.22, 5.71 → 3.22 and 5.89 → 3.22 MeV transitions are of M1 character, perhaps with E2 radiation mixed in. A comparison of the E1 and M1+E2 radiative widths of the $E_x = 5.71$ and 5.89 MeV levels shows that for both levels the M1+E2 width is about twice as large as the E1 width.

Recently, Van der Leun [14]) showed that in s-d shell nuclei M1 radiation is, on the

† In general this is not true. However, it was verified that $J(6.15) = \frac{3}{2}$ and radiation of M1+E2 character in either the C → 6.15 or 6.15 → 3.22 MeV transition, always gives $A_2 \leqq 0.07$ for the 2.49 and 2.38 MeV γ rays.

average, a bit stronger than E1 radiation. The ratio of the M1 and E1 widths for ^{33}S is expected to be 1.5. The ratio observed here agrees well with this phenomenological expectation value.

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