

## Références

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SPIN AND PARITY OF THE 3.13 MeV LEVEL IN  $P^{31}$ 

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The information on energies, spins and parities of  $P^{31}$  levels up to  $E_x = 4.2$  MeV, as of 1962<sup>1)</sup>, is presented in fig. 1. The spin of the 3.41 MeV level has recently been established as  $J = \frac{1}{2}^-(2, 3)$ .

$E_x$	$J^\pi$
4.188	$5/2^+$
3.414	$3/2^+$
3.505	$3/2^+$
3.292	$5/2^+$
3.133	$3/2^+$
2.232	$5/2^+$
1.265	$3/2^+$
	$1/2^+$

$^{31}P$

Fig. 1. Level scheme of  $P^{31}$ , as of 1962.

A second  $J^\pi = \frac{1}{2}^+$  state in  $P^{31}$  at relatively low excitation energy, predicted by the Nilsson scheme<sup>4)</sup>, by the vibrational model<sup>5)</sup>, and by a recent shell model calculation of  $(2s_{1/2})^n(1d_{3/2})^m$  states<sup>6)</sup>, has not yet been identified.

For some times it was thought that  $J^\pi = \frac{1}{2}^+$  should be assigned to level (3) at 3.13 MeV. Measurements by Hoogenboom<sup>7)</sup> of  $\gamma$ - $\gamma$  angular correlations at the  $Si^{30}(p, \gamma)P^{31}$   $E_p = 498$  and 670 keV resonances gave  $\frac{1}{2}^+$  as the most probable

value, without excluding, however,  $J^\pi = \frac{3}{2}^+$ . The  $\frac{3}{2}^+$  assignment to level (3) resulted from the observed anisotropic angular distribution of the 3.13 MeV  $\gamma$  ray<sup>4)</sup> at the 983 keV resonance in the same reaction. Recent angular correlation measurements<sup>2, 8)</sup> gave no new information. They are in perfect agreement with  $J^\pi = \frac{1}{2}^+$ , but never exclude  $\frac{3}{2}^+$ .

Actually, one can prove by closer inspection of the theoretical expressions for the angular correlation, that, if the spin of level (3) is  $\frac{1}{2}$ , the spin determination by angular correlation measurements alone can never be unique. Exclusion of a  $J = \frac{3}{2}$  assignment is impossible. Mixing ratios can always be found for the  $(\gamma) \rightarrow (3)$  and  $(3) \rightarrow (0)$  transitions, such that the theoretical expressions fit all the experimental data<sup>†</sup>.

This difficulty can be circumvented by a measurement of the direction-polarization correlation of the  $(\gamma) \rightarrow (3)$  transition. In the following such a measurement will be described, yielding the result that the spin and parity of level (3) are  $J^\pi = \frac{1}{2}^+$ , and not  $\frac{3}{2}^+$ .

The measurement was performed at the 498 keV  $Si^{30}(p, \gamma)P^{31}$   $J^\pi = \frac{3}{2}^+$  resonance. Protons were accelerated with the Utrecht 850 keV Cockcroft-Walton generator. The Compton scattering polarimeter was almost identical to that used by

† There are two exceptions to this rule. The  $J = \frac{3}{2}$  possibility can be excluded if the  $A_2$  and  $A_4$  coefficients in a Legendre polynomial development of the  $(\gamma) \rightarrow (3)$  angular distribution fulfill one of the following requirements: a)  $A_2 < -0.60$  (if the resonance spin is  $\frac{3}{2}$ ); b)  $A_4$  is measurably different from zero (if the resonance spin is  $\frac{3}{2}$ ). Such unused coefficients have not yet been encountered in the  $Si^{30}(p, \gamma)P^{31}$  reaction.

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Suffert<sup>9)</sup> in this laboratory. It incorporates a NaI scattering crystal (5 cm long and 5 cm diameter) below the target (with the proton beam coming in horizontally), and two NaI counters (10 cm long and 10 cm diameter) to detect the scattered radiation. The electronics used with the polarimeter was arranged according to a suggestion by Hazewindus<sup>10)</sup>. The pulses from the scattering crystal and either of the two detecting crystals are added in a summing circuit and stored in 100 channels of a 400-channel pulse analyser. The analyser gate only transmits pulses for storage if a) the pulses from the two crystals are in coincidence ( $\tau = 1.0 \mu$ ), b) the pulse from the detecting crystal has an amplitude between  $E_\gamma = 0.6$  and  $0.9$  MeV. With a routing system the pulses of the two detecting crystals A and B, at azimuthal positions of  $0^\circ$  and  $90^\circ$ , respectively, are stored simultaneously, each in 100 channels. These measurements are alternated with measurements where the counting system has been rotated over  $90^\circ$ , such that counter A is at  $-90^\circ$  and counter B at  $0^\circ$ . After the measurement the spectra at  $-90^\circ$  and  $90^\circ$ , and the two spectra at  $0^\circ$  are added separately. A conventional gain stabilizer was used for the scattering counter. The stabilizer was adjusted on the photopeak of the 662 keV  $\gamma$  ray from a  $\text{Cs}^{137}$  source put just above the target. A correction for eccentricity, only 2.2%, was determined by performing an analogous measurement at the  $E_p = 622$  keV,  $J = \frac{1}{2}$  resonance, emitting isotropic and unpolarized radiation.

The resulting spectra from a 60 hour run, together with the decay scheme of the 498 keV resonance, are given in fig. 2. It shows that the full-energy peak at 4.64 MeV, corresponding to the  $(\gamma) \rightarrow (3)$  transition is more intense at  $90^\circ$  than at  $0^\circ$ , corresponding to positive polarization  $P$ . The final value, after correcting for eccentricity and for the finite polarization detection efficiency of the polarimeter, taking into account solid angle attenuation, is  $P = +0.60 \pm 0.25$ .

This value has to be compared with the predicted polarizations, following from the measured  $\gamma_3$  angular distribution, for different spin assignments to level (3). This angular distribution is difficult to measure directly, because of the strong Compton contributions in the pulse spectrum from higher energy  $\gamma$  rays. Instead,  $\gamma$ - $\gamma$  angular correlations were measured of the  $(\gamma) \rightarrow (3) \rightarrow (0)$  cascade in four different geometries. The angular correlations in geometries II and VI (for the notation, see ref. 3) were found to be isotropic within the experimental error. In this case the angular correlation in geometries I and V

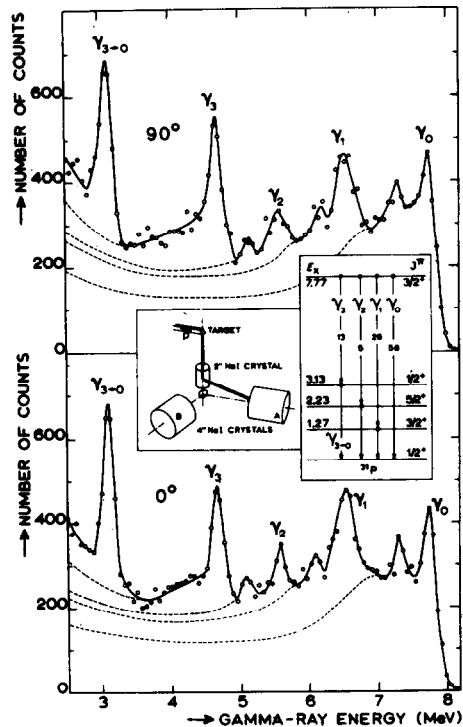


Fig. 2. Sum-pulse spectra (see text) at azimuthal angles of  $0^\circ$  and  $90^\circ$ , at the  $E_p = 498$  keV  $\text{Si}^{30}(p, \gamma)\text{P}^{31}$  resonance. The 4.64 MeV peak is more intense at  $90^\circ$  than at  $0^\circ$ , which points to positive polarization of  $\gamma_3$ . The  $\gamma_0$  transition has also positive polarization, while  $(3) \rightarrow (0)$  is unpolarized. The inserts show the polarimeter used in this experiment, and the branching of the  $E_p = 498$  keV  $\text{Si}^{30}(p, \gamma)\text{P}^{31}$  resonance.

should both be identical with the  $\gamma_3$  angular distribution. The  $P_2(\cos \theta)$  coefficients for I and V were found to be almost equal, with an average value  $A_2 = -0.41 \pm 0.05$ .

The corresponding E2-M1 amplitude mixing ratio's and predicted values of the polarization for the two spin possibilities,  $J = \frac{1}{2}$  and  $\frac{3}{2}$ , of level (3), are given in table 1.

Table 1  
Comparison between predicted and measured polarizations of the  $(\gamma) \rightarrow (3)$  transition.

$J^\pi(\gamma) \rightarrow J^\pi(3)$	Possible $x$ -values for $(\gamma) \rightarrow (3)$	Predicted polarization	Measured polarization
$\frac{3}{2}^+ \rightarrow \frac{1}{2}^+$	$-0.05 \pm 0.02$	$+0.66 \pm 0.03$	$+0.60 \pm 0.25$
	$+1.9 \pm 0.2$	$-0.64 \pm 0.05$	
$\frac{3}{2}^+ \rightarrow \frac{3}{2}^+$	$+0.64 \pm 0.06$	$-0.64 \pm 0.03$	$+0.60 \pm 0.25$
	$+3.0 \pm 0.5$	$-0.24 \pm 0.04$	

The measured polarization is seen to decide uniquely in favour of the  $\frac{1}{2}^+$  assignment to level (3), and to choose the small mixing ratio,  $x = -0.05 \pm 0.02$ , from the two possibilities for  $\gamma_3$ .

From the measurements presented in fig. 2 one can also deduce the polarization of  $\gamma_0$  as  $P = +0.35 \pm 0.27$ . A direct measurement of its angular distribution yields  $A_2 = -0.423 \pm 0.010$ .  $A_4 = 0$ . These data, combined with the measured strength  $^1$ , determine the resonance parity as even, since odd parity would entail an M2 component in  $\gamma_0$  of at least 5 Weisskopf units. Analogous reasoning, also using the known life-time of level (3)  $^{11}$ , then excludes odd parity for level (3), for either spin possibility  $J = \frac{1}{2}$  or  $\frac{3}{2}$ .

The (3)-(0) transition was found to have zero polarization, within the experimental error, corresponding to expectation if  $J(3) = \frac{1}{2}$ .

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