RESONANCES OF THE $Si^{29}(p, \gamma) P^{30}$ *REACTION*

Yu. P. ANTUF'EV, A. K. VAL'TER, A. N. L'VOV, E. G. KOPANETS, and S. P. TSYTKO

Physico-technical Institute, Academy of Sciences, Ukrainian S.S.R.

Submitted to JETP editor August 17, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **42**, 386-391 (February, 1962)

The relative yield of γ rays from $Si^{29}(p, \gamma) P^{30}$ was measured in the proton energy range 1.3 — 1.5 MeV. Five resonances were detected, two of which (at 1375 and 1500 keV) are studied in detail. From measurements of the γ-ray spectra and angular distributions the quantum characteristics of the excited P^{30} levels at 6.892 MeV ($I^{\pi} = 1^+$, T = 0) and 7.014 MeV ($I^{\pi} = 2^+$, T = 0) have been determined. Schemes of γ transitions from these two resonance levels of P^{30} are proposed and discussed.

INTRODUCTION

THE reaction $Si^{29}(p, \gamma) P^{30}$ has been studied in [1,2], where the spectra and angular distributions of γ rays from resonances at proton energies of 326, 414, 696, and 729 keV were measured. Our earlier work[3] was performed with E_p = 1330 keV. In the present work we have continued to measure the relative yield of γ rays from $Si^{29}(p, \gamma) P^{30}$ in the proton energy range 1.3 — 1.55 keV, and have made a detailed study of the spectra and angular distributions of γ rays in two resonances at the proton energies 1375 and 1500 keV. The apparatus, technique, and procedure were almost identical with those described in [3].

RELATIVE YIELD OF γ RAYS

The relative yield of γ rays from the Si^{29} target was measured at 90° to the beam of 1.3 — 1.5 MeV protons. The results (Fig. 1) show five resonances at 1308, 1330, 1375, 1470, and 1500 keV. At least four of these resonances belong to the reaction $Si^{29}(p, \gamma) P^{30}$. There is still no reliable interpretation of the resonance at E_p = 1470 keV, for which the γ-ray spectrum has not been studied in detail. We investigated the resonance at E_p = 1330 keV in [3]. The resonance at E_p = 1308 keV in the given target does not appear to be completely resolved, and final measurements of the corresponding spectrum have not been obtained. We shall therefore confine ourselves to the resonances at 1375 and 1500 keV.

γ-RAY SPECTRA AND ANGULAR DISTRIBUTIONS

The 1375-keV resonance and 6.892-MeV level. The soft, intermediate, and hard portions of the spectrum at ϑ = 90° to the incident proton beam are shown in Fig. 2. The γ rays were measured both at the peak and at the base of the resonance. Figure 3 shows the hard portion of the spectrum after subtraction of the γ rays at the base. The difference spectrum is seen to be well represented by a sum of individual γ lines; only the γ lines resulting from this analysis are shown.

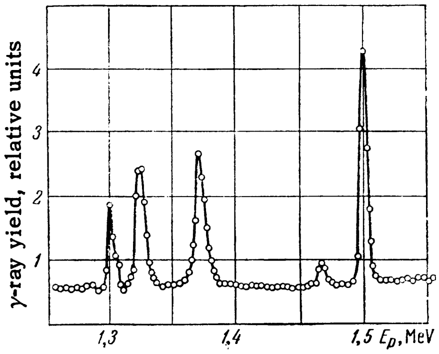


FIG. 1. Relative yields of γ rays from the reaction $Si^{29}(p, \gamma) P^{30}$

Table I gives the observed γ lines determined by the analysis of the resonance, the initial and final P^{30} levels, improved γ-transition energies corresponding to the lines, and the relative line intensities (the sum of the γ-transition intensities from the resonance level is taken as 100%).

The experimental error for all observed γ lines was taken to be ± 0.08 MeV; this is somewhat excessive, being almost twice as large as the error associated with the energy resolution of the NaI(Tl) crystal (70 mm in diameter, 50 mm long) and was taken roughly to equal ± 1 channel. The upper limit of error is given for the 0.684-MeV line.

A very weak line, observed very poorly, is given in parentheses.

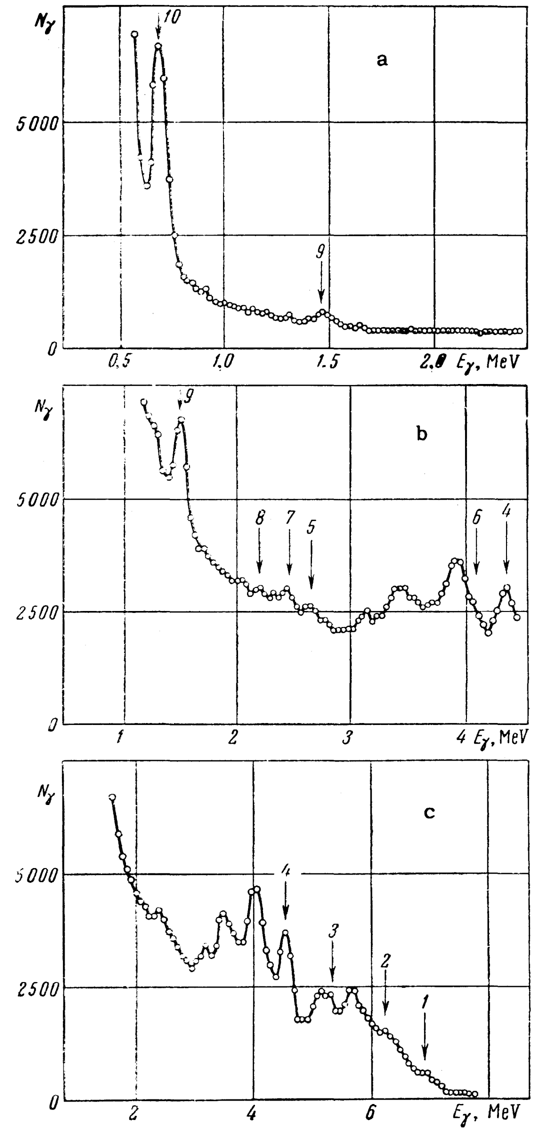


FIG. 2. Spectrum of γ rays from $Si^{29}(p, \gamma)P^{30}$ in resonance at E_p = 1375 keV. a – soft portion of spectrum, b – intermediate portion, c – hard portion.

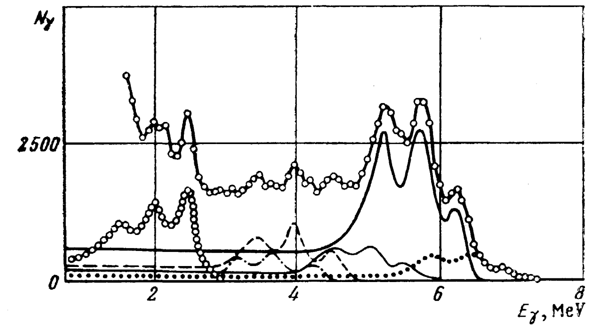


FIG. 3. Hard portion of the spectrum shown in Fig. 2, after subtracting the γ-ray background measured at the base of the resonance. The top curve through the experimental points is the measured spectrum. The dashed, dotted, continous, and dot-dash curves represent γ lines resulting from the analysis of the measured spectrum.

The angular symmetry

$$A = [W(0°) - W(90°)] / W(90°)$$

was measured for the 6.20-MeV line, the strongest line observed in this resonance spectrum; $W = 1 + A\cos^2\vartheta$ (dipole transition). We obtained $A = -0.63 \pm 0.05$.

When the measured result $A = -0.63 \pm 0.05$ is compared with values of A calculated for dipole transitions to a spin-zero level (Table II), the only good agreement with experiment is found for a transition from 1^+ to 0^+, with $A = -0.60$. All other calculated values of A lie far outside the limits of experimental error. Therefore spin and parity 1^+ can be assigned to the 6.892-MeV resonance level of P^{30}. It follows from the asymmetry measurements that this resonance level results from the capture of a proton with orbital angular momentum $l_p = 2$, with $J_c = 1$ for the spin of the reaction entrance channel.

The 1500-keV resonance and 7.014-MeV level. Figure 4 shows the soft, intermediate, and hard

Table I

No. of line	Energy of γ line, MeV	P^{30} level, MeV initial	P^{30} level, MeV final	γ-transition energy, MeV	Intensity, %	Transition type and multipolarity
1	6.89±0.08	6.892	0	6.892	4	E2 (or E2 + M1)
2	6.20±0.08	6.892	0.684	6.208	82	M1
3	5.44±0.08	6.892	1.45	5.442	4	E2 (or E2 + M1)
4	4.35±0.08	6.892	2.54	4.352	6	E2 (or E2 + M1)
5	2.70±0.08	6.892	4.18	2.712	4	E2 (or E2 + M1)
6	4.18±0.08	4.18	0	4.18		
7	2.54±0.08	2.54	0	2.54		
8	(2.25±0.08)	2.94	0.684	2.256		
9	1.45±0.08	1.45	0	1.45		
10	0.684±0.04	0.684	0	0.684		

Table II. Asymmetry coefficient A and angular distribution $W(\vartheta) = 1 + A\cos^2\vartheta$ for dipole transitions and integral spins

Spin of final state, J_f	Spin of initial state, J_i: 0	1	2	3
	l_p J_c A	l_p J_c A	l_p J_c A	l_p J_c A
0		0 1 0		
		2 1 —0.60		
		1 0 —1.00		
		1 1 +1.00		
1	0 0 0	0 1 0	2 0 —0.60	
	1 1 0	2 1 +0.43	2 1 —0.33	
		1 0 +1.00	1 1 —0.45	
		1 1 —0.33	3 1 —0.50	
		0 1 0	2 0 +1.00	2 1 —0.44
		2 1 —0.07	2 1 +0.43	4 1 —0.55
2		1 0 —0.14	1 1 +0.64	3 0 —0.50
		1 1 +0.08	3 1 +0.75	3 1 —0.39

Table III

No. of line	Energy of γ line, MeV	P^{30} level, MeV: initial	final	Transition energy, MeV	Intensity, %	Transition type and multipolarity
1	5.05±0.08	7.014	1.97	5.044	25	
2	4.45±0.08	7.014	2.54	4.474	15	
3	2.83±0.08	7.014	4.18	2.834	60	*M1*
4	2.5±0.08	2.54	0	2.54		
5	2.25±0.08	2.94	0.706	2.236		
6	1.97±0.08	1.97	0	1.97		
7	1.70±0.08	2.54	0.706	1.734		
8	1.45±0.08	2.94	1.45	1.49		
9	1.25±0.08	4.18	2.94	1.24		
10	0.70±0.02	0.706	0	0.706		

portions of the measured spectrum for this resonance. Table III gives the γ lines and corresponding transitions between P^{30} levels resulting from an analysis of this spectrum similar to that for the other resonance.

The measured asymmetry was $A = 1.07 \pm 0.10$ at 2.83 keV, the most intense line in this resonance. Since this line represents a transition from the resonance level 7.014 MeV to the 4.18-MeV level with known spin and parity 2^+, this experimental value of A must be compared with all possible values calculated for transitions to a spin-2 level. A comparison with Table II shows that the only good agreement with experiment occurs for a transition from spin-2 to spin-2 for which we have the calculated value $A = +1.00$. All other values of A lie far outside the experimental errors. Therefore spin and parity 2^+ can be assigned to the 7.014-MeV resonance level. It also follows from our asymmetry measurements that this level and the corresponding resonance result from the capture of a proton with orbital angular momentum $l_p = 2$, with $J_c = 1$ for the entrance channel.

γ-RAY DECAY SCHEMES AND DISCUSSION OF RESULTS

The measured γ-ray spectra and angular distributions provide a basis for setting up a decay scheme of the two P^{30} resonance levels at 6.892 and 7.014 MeV (Figs. 5 and 6).

The decay scheme for the 6.892-MeV level ($E_p = 1375$ keV) shows the pronounced difference between the transition intensities to the ground and first few low-lying P^{30} levels having isotopic spins $T = 0$ and 1. The most intense dipole transition (M1 with 82%) goes from the resonance level to the 0.684-MeV level (0^+ with $T = 1$); very weak transitions (apparently E2 with 4 — 6%) go to the other levels with $T = 0$. We can thus assign isospin 0 to the 6.892-MeV level; this follows

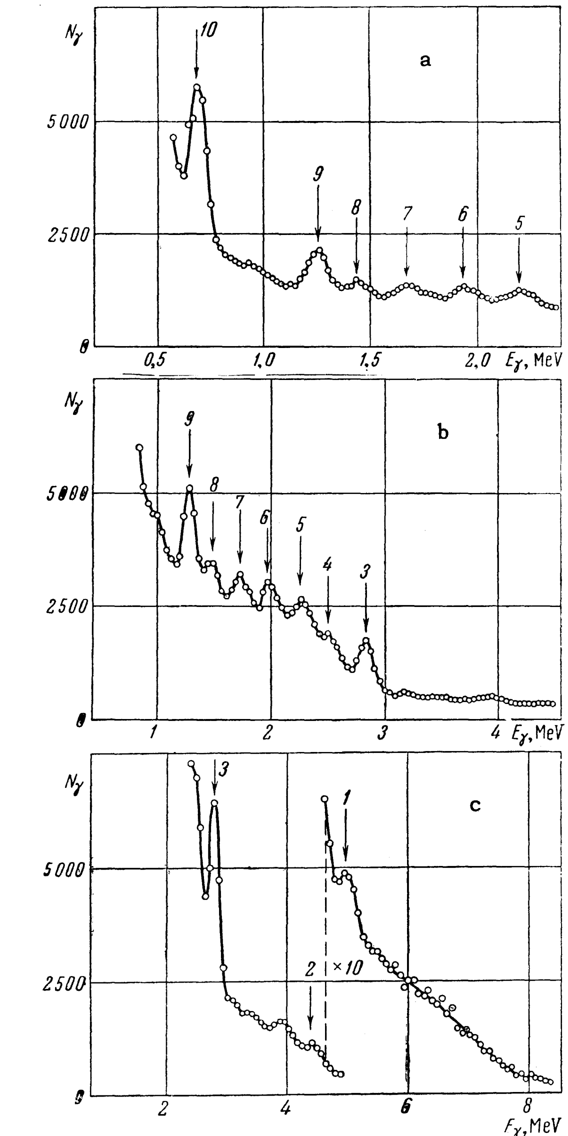


FIG. 4. Spectrum of γ rays from $Si^{29}(p, \gamma)P^{30}$ in the resonance at E_p = 1500 keV. a – soft portion of spectrum, b – intermediate portion, c – hard portion.

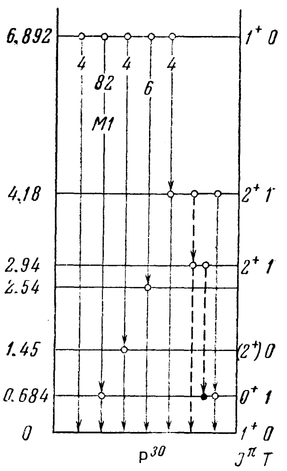
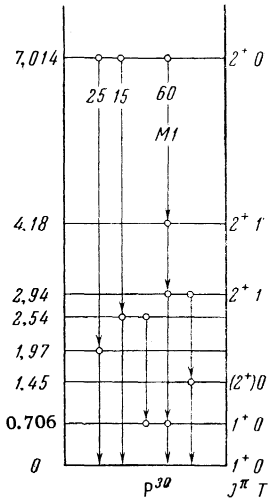


FIG. 5. Decay scheme and γ transitions from the 6.892-MeV P^{30} resonance level.

from the isospin selection rules for dipole transitions of self-conjugate nuclei. The other isospin assignment (T = 1) for this resonance level cannot be brought into agreement with the well observed intense M1 transition, for which $\Delta T = 0$ is forbidden by the selection rules.

FIG. 6. Decay scheme and γ transitions from the 7.014-MeV P^{30} resonance level.



The decay scheme of the 2^+ level at 7.014 MeV also shows that a M1 transition is most intense, going to the 4.18-MeV level (2^+, T = 1). It follows that T = 0 must be assigned to the 7.014-MeV resonance level, since T = 1 would be inconsistent with the well observed M1 transition and with the isospin selection rules, according to which $\Delta T = 0$ is forbidden in M1 and E1 transitions of self-conjugate nuclei.

There is a great difference between the decay schemes for the two given P^{30} resonance levels. The most intense M1 transition from 6.892 MeV goes to the first excited level at 0.684 MeV, whereas the intense M1 transition from 7.064 MeV goes to the 4.18-MeV level lying considerably above many other P^{30} levels. This interesting circumstance provides a convenient opportunity for testing the asymptotic selection rules recently proposed in the literature.[4,5]

---

[1] Endt, Kluyver, and Van der Leun, Phys. Rev. **95**, 580 (1954).

[2] C. Van der Leun and P. M. Endt, Phys. Rev. **110**, 96 (1958).

[3] Val'ter, Antuf'ev, Kopanets, L'vov, and Tsytko, Report at 11th Conference on Nuclear Spectroscopy, Riga, 1960; JETP **41**, 1449 (1961), Soviet Phys. JETP **14**, 1035 (1962).

[4] M. E. Voĭkhanskii, JETP **33**, 1004 (1957), Soviet Phys. JETP **6**, 771 (1958).

[5] M. E. Voĭkhanskii and L. K. Peker, Izv. AN SSSR Ser. Fiz. **25**, 297 (1961), Columbia Tech. Transl. p. 284.

Translated by I. Emin
61