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PHOTOPROTON CROSS SECTIONS FOR THE NUCLEUS ^{31}P*

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ABSTRACT

The energy spectra of photoprotons from the $^{31}P(\gamma,p)^{30}Si$ reaction have been measured at seven angles simultaneously, in the energy interval between 17 and 25 MeV. By fitting a sum of Legendre Polynomials to the differential cross sections, the total $\sigma(\gamma,p_o)$ ground state cross section is obtained in which many resonances are observed.

ÖZET

$^{31}P(\gamma,p)^{30}Si$ reaksiyonu protonlarının enerji spektrumları, yedi açıda, 17 ve 25 MeV enerji aralığında ölçülmüştür. Diferansiyel tesir kesitlerine Legendre Polinomları uygulanarak bir çok rezonansların gözlendiği toplam taban enerji düzeyi tesir kesiti $\sigma(\gamma,p_o)$ bulunmuştur.

INTRODUCTION

During the past twenty years, most of the experimental photonuclear studies of the ^{31}P nucleus were performed with (γ,n) reactions. It has been reported by many researchers that the experimental data on the $^{31}P(\gamma,p)$ reaction are scarce due to the experimental difficulties caused by a continuous bremsstrahlung spectrum of photons and since monoenergetic photons are hard to obtain /8,11,12,15,18,20/.

The nucleus ^{31}P is a light, stable atomic nucleus that exists in nature with an abundancy of 100 % and in metallic form. It has one proton and two neutrons in the $2s_{1/2}$ valence shell in the independent particle shell model. Thus it is one of the 2s-1d shell nuclei

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which is an odd Z-nucleus. Furthermore it is difficult to apply the particle-hole model to non-closed shell nuclei, few theoretical calculations have been performed for nuclei such as ^{31}P /19/. Therefore it is tempting to investigate the $^{31}P(\gamma,p)^{30}Si$ reaction in order to obtain more clear information about the (γ,p) reaction mechanism and about the structure of ^{31}P in the giant dipole resonance region.

EXPERIMENTAL

A natural ^{31}P foil with a thickness of 4.6 mg/cm^2 was irradiated with a beam of bremsstrahlung photons produced at the 70 MeV linear electron accelerator of the Ghent State University. The general experimental arrangement is shown in Fig.1. The ^{31}P was centered in a vacuum reaction chamber in which seven uncooled 3 mm thick Si(Li) detectors were placed circumferentially at different angles between 37^0 and 143^0. A schematic sketch of the reaction chamber is shown in Fig.2.

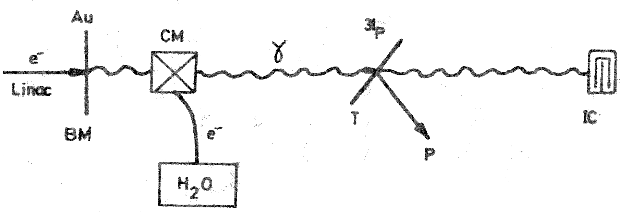

Fig. 1. General layout of the experimental arrangement. Linac: Linear accelerator, BM: bremsstrahlung target, CM: cleaning magnet, T: photoproton target, IC: ionization chamber.

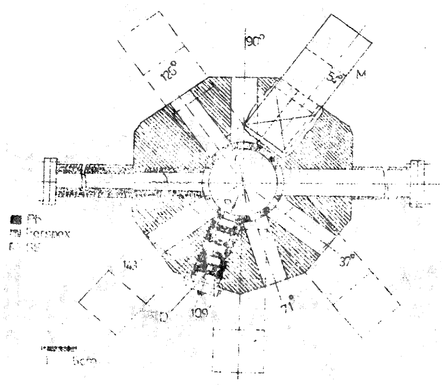

Fig. 2. Schematic drawing of the photoproton detection chamber. T: target, D: detector, M: magnet.

For suppressing the electron γ-background permanent magnets were placed over the detector channels. The γ-radiation was monitored by a NBS-P2/4 type ionization chamber. The electronics used for the accumulation and processing of the proton signals from all detectors, consist of the following: A charge sensitive preamplifier and a main amplifier having integration and differentiation time constants of 0,3 s ; they were placed close to the detectors. The outputs from the seven amplifiers go to an 8-input multiplexer-router unit which works in combination with a single 512-channel analog-to-digital converter (ADC). The pulse height data are transfered to the computers for analysis. A diagram of the electronics is shown in Fig. 3.

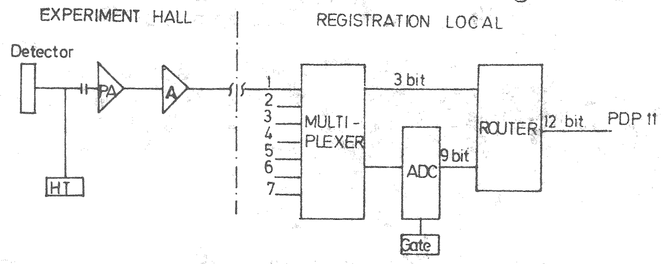

Fig. 3. Diagram of the electronics. HT: high tension, PA: preamplifier, A: amplifier, ADC: analog-to-digital converter, PDP 11: Computer.

RESULTS

It is known that there is 2.23 MeV energy difference between the first excited and ground states in the residual nucleus ^{30}Si, so when ^{31}P is excited via the continuous bremsstrahlung, one can say that the protons which are situated in the spectrum in the energy region between the end point and 2.23 MeV lower than the end point belong to the (γ,p_o) ground state spectrum. The end point energies in our (γ,p) experiment, run up from 17 to 25 MeV in steps of 1 MeV. For every end point energy, a (γ,p_o) cross section can be determined in an excitation energy region with a width of 2.23 MeV. Thus, the proton spectra dN/dT_p taken at seven angles can be converted to the differential cross section if one has the knowledge of both the total integrated photon intensity and the spectral distribution. As bremsstrahlung spectrum, the Schiff's integrated over all angles spectrum is used /14/.

Furthermore by fitting the differential cross sections with a sum of Legendre polynomials one can write:

$$\frac{d\sigma}{d\Omega}(E,\Theta) = A_O(E) \left| 1 + \sum_{l=1}^{4} a_l(E)\, P_l(\cos\Theta) \right|$$

where $a_l(E) = A_l(E)/A_O(E)$ are the normalized coefficients. A pleasant feature of the Legendre expansion is that the total (γ,p_O) ground state cross section can be obtained by integrating the above expression over the total solid angle:

$$\sigma_{tot}(\gamma,p_O) = 4\Pi A_O(E) = \frac{d\sigma}{d\Omega}(E,\Theta)\, d\Omega$$

The total integrated-over-angles cross section $\sigma(\gamma,p_O) = 4\Pi A_O$ is given in Fig. 4.; this exhibits a giant resonance structure with a maximum of 0.18 fm^2 at 20.8 MeV. The statistical uncertainties are depicted and amount to 8 %. The energy integrated cross section for the ground state channel between 14.8 MeV and 24.8 MeV energies amounts to 1.29 ± 0.01 MeV.fm^2. This is about 2.5 % of the TRK dipole sum rule (which is given by 6NZ/A and is 46.5 MeV. fm^2 for ^{31}P). This means that most of the decay of giant dipole states goes through non-ground states of the residual nucleus ^{30}Si.

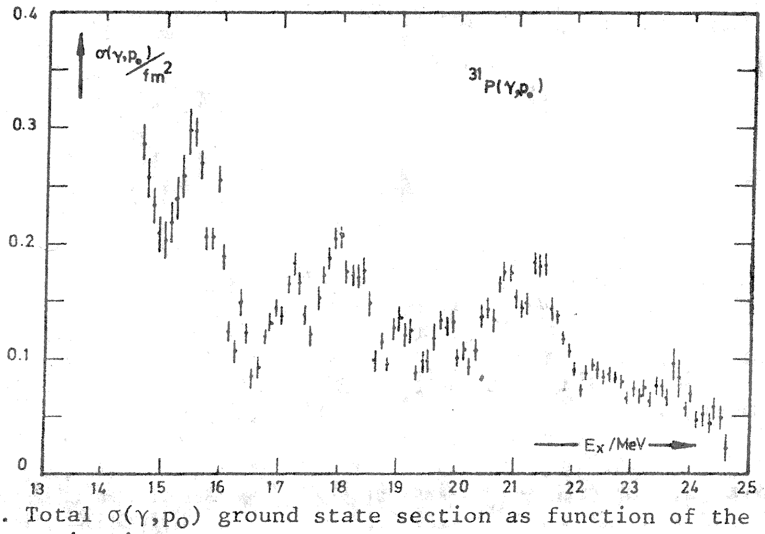

Fig. 4. Total $\sigma(\gamma,p_O)$ ground state section as function of the excitation energy.

In Table-1 the energies of the observed structures in the $\sigma(\gamma,p_O)$ is compared with those of Tsubota's /19/ and Cameron's /4/ differential ground state cross section both at 90^0. The results of Cameron are converted to the (γ,p_o) cross section by the principle of detailed balance /7/. The correspondence is striking between both results of Tsubota and Cameron, and the present data, within the energy resolution. In the same table, the energies of the structure observed in the $^{31}P(\gamma,n)$, $^{31}P(\gamma,n_o)$ reactions of various authors are also shown. For most of the resonances the correspondence between our results and the photoneutron data is fair.

This similarity of the structure in the $^{31}P(\gamma,p_o)$ ^{30}Si reaction suggests the similar reaction mechanism concerning to the valence nucleons. The structure below 20 MeV in the ground state cross section could then be possibly explained by the $(2\ s_{1/2})^{-}(2\ p_{1/2})$ and $(2\ s_{1/2})^{-}(2\ p_{3/2})$ single particle excitations /16,17,19/. The fact that the decay mechanism of the ^{31}P nucleus for the (γ,p_o), (γ,n_o) and (γ,n) channels, as seen from Table-1 does not seen essentially different, confirms this argument /5,10,11/. Moreover the strength of the ground state is well reproduced by the shell model calculations of Wildenthal et al. /21, 22/.

CONCLUSION

The photoproton cross sections were measured in the energy interval between 14 and 25 MeV using a bremsstrahlung photon beam produced by 70 MeV electrons from the linear accelerator.

It was possible to determine the absolute cross sections for the $^{31}P(\gamma,p)^{30}Si$ reaction as a function of the excitation energy. Data on the latter are scarce in the literature.

Resonances observed in the total ground state cross section were in good agreement with the photoneutron results taken from the literature, they correspond satisfactorily to the (γ,p_o) results of Tsubota /19/ as well as to the data from the inverse (p,γ_o) reaction of Cameron et al. /4/. The integrated ground-state cross section in the region 14.8 to 24.8 MeV is about 1.3 MeV.fm^2. This represents only circa 2.5 % of the TRK dipole sum rule (6NZ/A MeV.fm^2), which indicates important non-ground state photoproton transitions /1, 2/. Via the construction of an artificial monoenergetic photon beam one can obtain the absolute cross sections for a number of non-ground state reaction channels /3/.

Table 1. Resonances observed in ^{31}P photoneutron and photoproton cross section measurements.

E (MeV)	Mutsuro et al. (γ,n) bremsstrahlung [13]	Ishkhanov et al. (γ,n) bremsstrahlung [9]	Devos et al. (γ,n) bremsstrahlung [5]	Veyssière et al. (γ,n) monochromatic's [20]	Mishina et al. (γ,n) n-spectra [11]	Kawamura et al. (γ,n_0) n-spectra [10]	Gellie et al. (γ,n_0) n-spectra [6]	Tsubota et al. (γ,p_0) p-spectra [19]	Cameron et al. (p,γ_0) [4]	This work (γ,p_0) bremsstrahlung
13.0			(13.0)							
			(13.3)						13.0	
	13.5						13.4		13.4	
		13.7	13.7							
				13.8						
14.0					14.2		14.0			
		(14.3)	14.3		14.3			(14.3)		
				14.5	14.5		14.5		14.5	
	14.6					14.7		14.7		14.6
		14.8	14.8		(14.8)	(14.9)	14.8			
15.0				(15.1)		(15.1)			15.0	
						(15.2)	15.3			
		15.4	15.4	15.5	(15.5)			15.5	15.4	15.5
							15.7			
	15.8		(15.8)			15.8			15.8	15.9
16.0			16.1		(16.1)			16.0		
		16.2		(16.2)					16.3	16.3
					(16.8)	16.8	16.9		16.8	(16.9)
17.0	(17.0)		(17.0)	17.1	(17.1)	(17.0)			17.1	
						17.3		17.3		17.2
	17.5									
			17.6			17.6				
		17.7		17.7	17.7	17.7			17.9	17.9
18.0						(18.0)		18.0		
				18.2		(18.2)			(18.2)	
		18.4	18.5		18.5	(18.5)			(18.4)	(18.4)
						18.7			18.6	
19.0	19.0			19.1	19.1				19.1	19.1
		19.3				19.2	19.3	19.2		
			19.4							
								19.6	19.6	19.7
						19.9				
20.0										
	20.3	20.5				(20.3)				(20.5)
								20.6	20.6	20.8
21.0						21.0				
		21.3	21.3	21.3				21.3	21.4	21.4
22.0		22.0		22.0				22.0		
			22.6						22.3	22.4
23.0								23.0		

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