Total Photoabsorption Cross Section of The Nucleus ^{31}P

Abdulkadir AKSOY *

ÖZET

Bu çalışmada ölçülen ^{31}P çekirdeği toplam fotoproton tesir kesiti, daha önce bilinen toplam fotonötron tesir kesitine eklenerek, bu çekirdeğin toplam fotoabsorpsiyon tesir kesiti için bir değer bulunmuştur. Bunun için Lorentz-eğrileri deneysel verilere yakıştırılmış ve integre edilmiş sonuç, toplam kuralın verdiği teorik değerle karşılaştırılmıştır.

SUMMARY

A value for the total photoabsorption cross section of the nucleus ^{31}P is obtained by adding the photoproton cross section measured in this work to the total photoneutron cross section previously known. For that Lorentz-lines are fitted to the experimental data and the integrated result is compared with the value given by the sum rule.

INTRODUCTION

In a photonuclear reaction an incident photon is absorbed by a nucleus whereby a particle such as a proton, neutron, etc. can be emitted out of the nucleus. To study a nucleus by means of the electromagnetic radiation is a useful tool for investigation of nuclear properties.

In past years most of the experimental photonuclear studies of the ^{31}P nucleus were performed with $(\gamma\ n)$ reaction. The available experimental data on the (γ, p) reaction of this nucleus are scarce in the literature. In the Giant Dipole Resonance (GDR) region 90 % of the absorption is exhausted by the (γ, p) photoproton and (γ, n) photoneutron reaction while the remaining 10 % goes through the $(\gamma, 2n)$, (γ, np), (γ, fission), etc. reactions (1).

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* Sakarya D.M.M. Akademisi, Dr.

EXPERIMENTAL TECHNIQUE

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. Photoprotons were detected by means of uncooled Si(Li) detectors at seven different angles between 37° and 143°. Photoproton spectra were measured at several bremsstrahlung end point energies between 17 and 25 *MeV*, going up in *1MeV* steps. After shaping and amplification, the signals from the various detectors were multiplexed into a 512-channel analog-to-digital converter and subsequently routed into the memory of a PDP-11 computer. The further details of the experimental setup are described in a previous paper (2).

METHODS OF ANALYSIS

In order to obtain the total (γ, p) cross section the following method is applied. For each angle, we added the protons which are detected by the detector. So we obtained the differential of proton yield at one angle $\frac{dY}{d\Omega}$. We do this process for all angles; θ=37°, 54°, 71°, 90°, 109°, 126° and 153°. So that we have the seven values of $\frac{dY}{d\Omega}$ versus of the angles θ. Then a sum of Legendre polynomials (3) can be fitted to the 7 points and then the total number of protons for an end point energy can be obtained by integrating of the yield curves over the solid angle Ω:

$$Y = \int_{4\pi} \frac{dY}{d\Omega}\, d\Omega$$

Since the photoproton spectra were measured at various bremsstrahlung end point energies going up in 1 *MeV* steps, from 17 up to 24 *MeV*, for each end point energy we applied the Penfold and Leiss analysis method (4) to the proton spectra, in order to convert the yield of protons to the total (γ, p) photoproton cross section.

RESULTS AND DISCUSSION

The total (γ, p) cross section was unfolded using the Thies analysis (5). The result of the total proton yield for an analysis interval of 3 *MeV* is shown in Figure 1. The errors are statistical only. The horizontal error is due to the analysis interval. The cross section shows two resonances each with a width of about 7 *MeV*, situated at the energies E_x=19.5 and

22.5*MeV*, respectively. The first peak possesses a maximum of 2.25 fm^2 while the second has a maximum of 2.66 fm^2. Lorentz-lines are fitted to the points. The parameters are the following:

$E<=19.5$ *MeV*	$E>=22.5$ *MeV*
$\Gamma<=7$ *MeV*	$\Gamma>=7$ *MeV*
$\sigma<=1.244$ fm^2	$\sigma>=1.737$ fm^2

where E, Γ and σ are the resonance energy, the width (FWHM), and the magnitude of the cross section of both peaks at maximum, respectively. A Lorentz-line has the form:

$$\sigma_L = \frac{(E_x \Gamma)^2}{(E_x^2 - E_R^2) + (E_x \Gamma)^2}$$

where σ, E_R and Γ are the maximum, the resonance energy and the width of the resonance, respectively.

In Figure 2, together with our total σ (γ, p) cross section the total photoneutron cross section σ (γ, n) of Veyssière et al. (6) and the total σ (γ, p) photoproton cross section of Ishkhanov et al. (7) are shown. In both works two peaks can be seen. The strength of the peaks in Iskhanov's work is larger than that for the others and the results agree with each other as far as the place of the peaks is concerned.

The total integrated (γ, p) and (γ, n) cross sections are shown in Table 1. Our result is smaller than Ishkhanov's (γ, p) result (7) while his uncertainty is larger than ours. It is also seen that our σ (γ, p) value is larger than Veyssière's (6) σ (γ, n) value. This was expected since the threshold value of ^{31}P (γ, p) 7.29 *MeV* is lower than that for ^{31}P (γ, n) which is 12.3 *MeV*. The fact that there is a certain predominance of σ (γ, p) over σ (γ, n) cross section, is a characteristic feature in light nuclei (8, 9). In Table 1, the cross sections mentioned above are also compared with the classical TRK sum rule [6 NZ/A $MeV \cdot fm^2$] of Thomas, Reiche and Kuhn. Since for ^{31}P, $N=16$, $Z=15$ and $A=31$ then the TRK sum rule gives 46.5 $MeV \cdot fm^2$ (10).

In Table 2 the ratio of σ (γ, p) to σ (γ, n) of ^{31}P is given, Together with σ (γ, n) of Veyssière our result gives a nice agreement with the ratio obtained by Ishkhanov. Since the ratio of (γ, n) to (γ, p) of ^{31}P is 12.30/7.29=1.6, the ratio between cross sections might be a function of the ratio between thresholds of photoneutron and photoproton reactions, respectively. This was suggested by Veyssière et al. (6).

In the GDR region (i.e. between 10-25 *MeV*), the (γ, p) and (γ, n) reactions of ^{31}P are dominant in the decay of dipole states (1). So the sum of our result with the one of Veyssière may be used as an approximation for the total gamma-absorption cross section. The nuclear absorption cross section of ^{31}P amounts to 44.1 ± 0.6 $MeV \cdot fm^2$ calculated from the data of Dular et al. (11). This is lower than the value of TRK sum rule (46.5 $MeV \cdot fm^2$). On the other hand according to the recent calculations

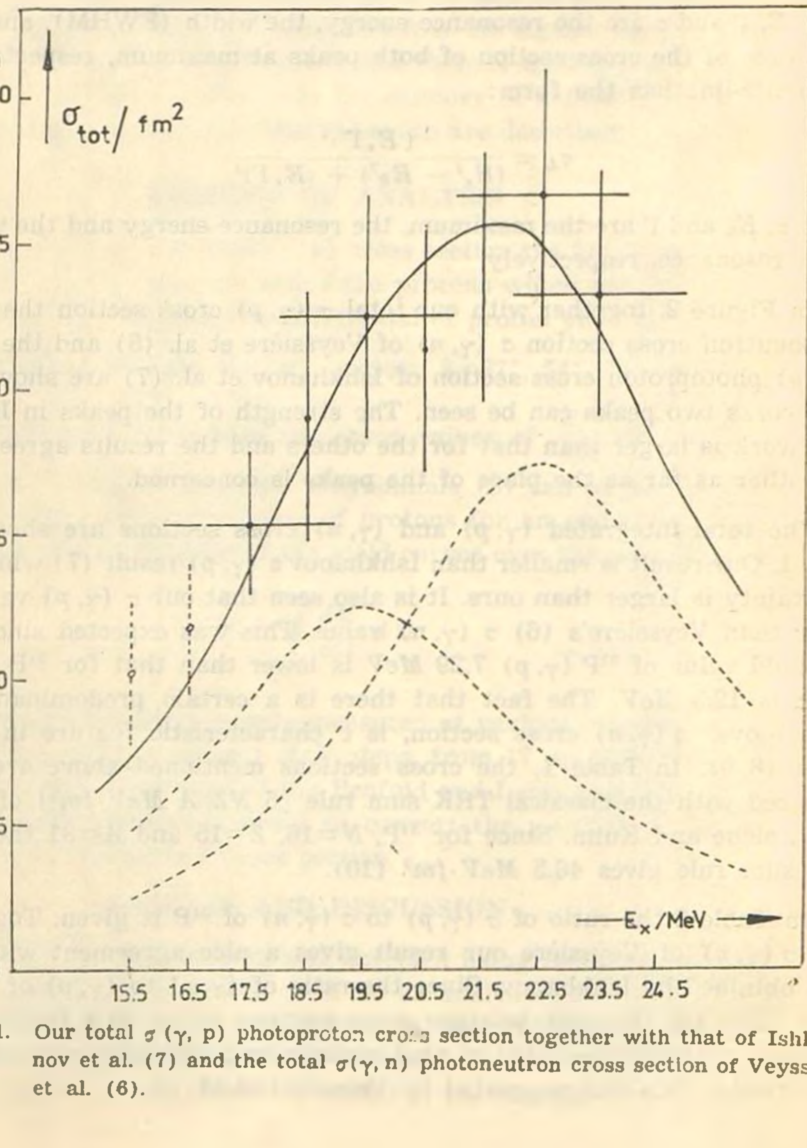

Figure 1. Our total $\sigma(\gamma, p)$ photoproton cross section together with that of Ishkhanov et al. (7) and the total $\sigma(\gamma, n)$ photoneutron cross section of Veyssière et al. (6).

done by Leonardi and Lipparini (12) the sum rule for ^{31}P turned out to be (5.3 NZ/A $MeV \cdot fm^2$) which gives 41 $MeV \cdot fm^2$. In that case the value of Dular exceeds the classical sum rule. The total photoneutron cross section of ^{31}P integrated between 0 and 30 MeV is given by Veyssière et al. (6) as about 16.4 $MeV \cdot fm^2$. This value together with our σ (γ, p) cross section amounts to nearly 33 ± 2.5 $MeV \cdot fm^2$. This is lower than 41 $MeV \cdot fm^2$ predicted by the sum rule. The difference may be due to the fact that our upper limit of integration is low (24 MeV).

On the other hand the total integrated cross section can also be estimated by using the Lorentz-lines fitted to the total (γ, p) cross section (See Fig. 1). This is done following the integral and using the ob-

$$\int_0^\infty (E_x)\, dE_x = \pi/2\, \sigma\, \Gamma$$

tained values for σ and Γ that are respectively $\sigma_< = 1.24$ fm^2, $\sigma_> = 1.7$ fm^2 and $\Gamma_< = \Gamma_> = 7$ MeV. So we obtain for the total integrated (γ, p) cross section σ_{tot} $(\gamma, p) = 32$ $MeV \cdot fm^2$. From the total (γ, n) cross section of Veyssière (see Fig. 2) we estimate the total energy integrated cross section in the following way. The ratio between the maxima of the two cross sections is

$$\frac{\sigma(\gamma, p)\,(E_x = 21.5\ MeV)}{\sigma(\gamma, n)\,(E_x = 21.5\ MeV)} \cong \frac{2.6}{1.8} = 1.4$$

By means of this ratio and our σ_{tot} (γ, p) estimated above, one can also estimate the integrated total (γ, n) cross section. It amounts to

$$\sigma_{tot}(\gamma, n) = \frac{\sigma_{tot}(\gamma, p)}{1.4} = 22\ MeV \cdot fm^2$$

Adding to the (γ, p) result we obtain for the total integrated absorption cross section.

$$\sigma_{tot}\ (\gamma, \text{absorption}) \simeq 32 + 22 = 54\ MeV \cdot fm^2$$

This last value can be compared with the value of the TRK sum rule (46.5 $MeV \cdot fm^2$). So the estimated value exceeds the classical TRK sum rule.

CONCLUSION

The integrated photoproton cross section of ^{31}P is obtained by measuring photoproton spectra between 17 and 24 *MeV*. The total (γ, p) cross section amounts to 16.6±2.5 $MeV \cdot fm^2$. This result was larger than the total photoneutron cross section given by the Veyssière's work (6). Adding our (γ, *p*) result to that of (γ, *n*), we have 33±2.5 $MeV \cdot fm^2$ which is lower than the value given by the TRK sum rule (46 5 $MeV \cdot fm^2$).

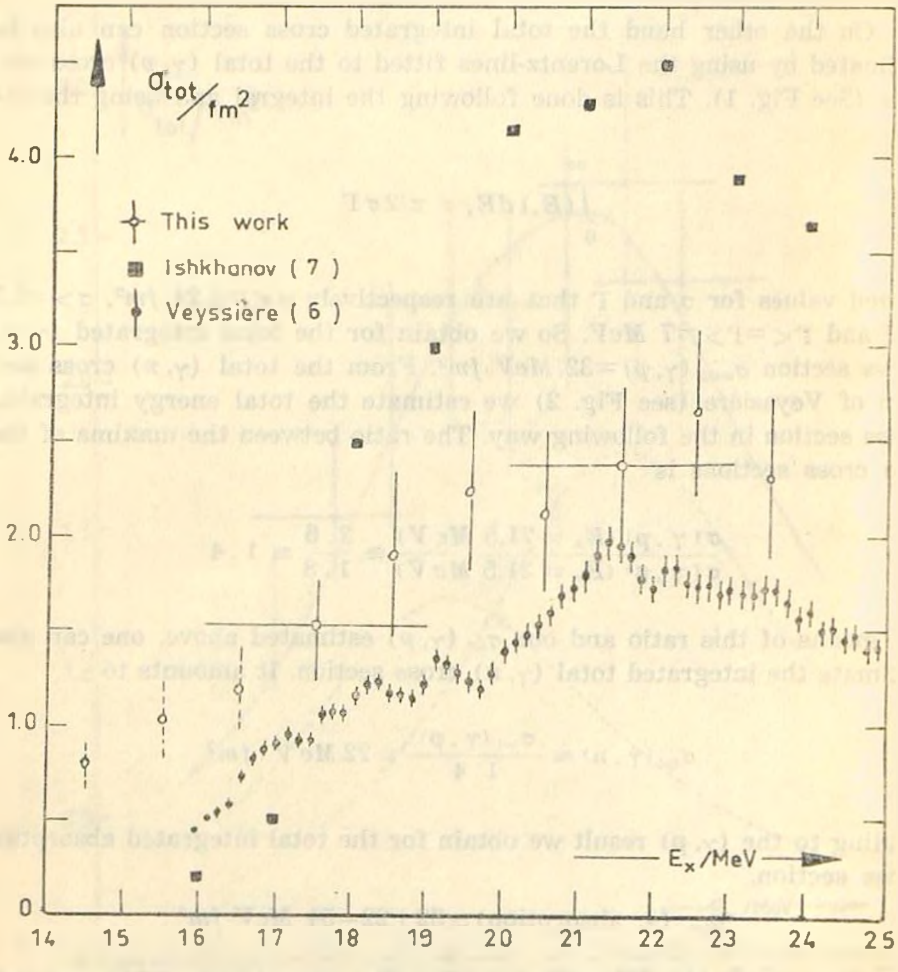

Figure 2. The total cross section for the $^{31}P(\gamma, p)^{30}Si$ reaction. Lorentz-lines are fitted to the points, The parameters are $E_< = 19.5$ MeV, $\Gamma_< = 7$ MeV, $\sigma_< = 1.244$ fm² and $E_> = 22.5$ MeV, $\Gamma_> = 7$MeV, $\sigma_> = 1.737$ fm².

Table 1 : Experimental integrated photoproton and photoneutron cross sections [in MeV. fm² and in % of TRK classical sum rule (6NZ/A MeV. fm²)].

Reaction	Experiment	$\int_{E_1}^{E_2} \sigma d E$ (MeV . fm²)	E_1 MeV	E_2 MeV
$^{31}P(\gamma, p)$	Ishkanov et al. (7)	25.7 ± 3.7 % 55	17	24
	Present experiment	16.6 ± 2.5 % 35	17	24
$^{31}P(\gamma, n)$	Ishkhanov et al. (7)	10.7 ± 1 % 23	12.4	22.5
	Veyssiere et al. (6)	11.7 % 25	17	24

Table 2 : The ratio of the integrated cross section of the $^{31}P(\gamma, p)$ reaction to that of the $^{31}P(\gamma, n)$ reaction.

$\left[\frac{\sigma(\gamma, p)}{\sigma(\gamma, n)}\right]_{31}$	Energy region (MeV)	ref.
1.6 ± 0.2	12.3 — 30	Ishkhanov et al. (7)
1.4 ± 0.2	17 — 24	Our results together with $\sigma(\gamma, n)$ of Veyssiere et al (6)

Moreover by using the Lorentz lines fitted to the data, we were able to integrate our total (γ, p) cross section in a better way. So we obtained 32 $MeV \cdot fm^2$ for the total photoproton cross section. Applying this method to the photoneutron result and taking the sum of both results, an estimation for the total photoabsorption cross section is calculated. This amounts to 54 $MeV \cdot fm^2$. So the estimated value exceed that implied by the TRK sum rule.

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