# LETTERS TO THE EDITOR

## RADIATIVE PROTON CAPTURE TO THE FIRST EXCITED STATE OF $^{29}$P NUCLEUS AT SUBBARRIER ENERGIES*

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*(Received May 16, 1985)*

Differential cross sections at 0° and 90° measured for $^{28}$Si(p, $\gamma_1$)$^{29}$P reaction at proton energy range 2.3–2.9 MeV have been analyzed in terms of the direct-semidirect capture model extended by the effective potential approach. Spectroscopic factor of the first excited state of $^{29}$P nucleus was found to be $0.10 \pm 0.05$.

PACS numbers: 25.40.Lw, 25.40.–h

In our recent study [1] of the $^{28}$Si(p, $\gamma$)$^{29}$P reaction at subbarrier proton energies it was shown, that the effective potential approach [2] could be successfully applied to the direct-semidirect (DSD) description of the excitation function and angular distributions of emitted gamma-quanta. Comparison of the theoretical excitation function and the experimental cross section data, which for the transitions to the ground state cover the energy range of 1.5–3.0 MeV [3, 4], allowed to extract the value of the spectroscopic factor of the final ground state. However, in the case of the $^{28}$Si(p, $\gamma_1$) transitions leading to the first excited state of the $^{29}$P nucleus ($J^\pi = 3/2^+$, $E^* \doteq 1.383$ MeV [5]), the experimental data were limited to the narrow 1.5–1.9 MeV region (the data covering the 2.09 MeV

* Partial financial support under Project 04.3.

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$J^\pi = 1/2^+$ resonance were not usable due to the limitation of the applied version of the DSD model assuming only E1 transitions in the $\gamma$-channel). Our previous model calculations [1] have shown that the experimental data could be reproduced in a satisfactory way with different values of the spectroscopic factor of the final state, the best-fit value being $S = 0.1$ ($C^2 = 1$), but a still acceptable fit was obtained with theoretically justified $S = 0.5$.

In this letter we present the experimental study of the $^{28}$Si(p, $\gamma_1$) reaction at proton energies 2.3–2.9 MeV, which cover the low energy part of the broad 2.8 MeV resonance ($J^\pi = 1/2^-$, $\Gamma \cong 0.40$ MeV). These experimental data together with those from the work of Terassi et al. [4] are compared with DSD model calculations.

The experiment was performed with a proton beam from the Warsaw 3 MeV VdG accelerator. Targets, prepared by evaporation of a natural $SiO_2$ on a tantalum backing, were placed at 45° with respect to the beam axis. The thickness of targets was 15–20 keV (at 45°). Two in-beam gamma-ray spectra were recorded simultaneously using two Ge(Li) detectors placed at 0° and 90° and standard electronic equipment connected to the ND 4420 microcomputer. For each energy the collected charge of proton beam (20–30 μA) was typically 2–4 C. The presence of oxygen in the target material allowed to determine precisely the energy of incoming protons according to the method proposed by Rolfs et al. [6]. Since the absolute excitation function of the $^{28}$Si(p, $\gamma_0$) reaction is known experimentally [3] and well described theoretically [1], the absolute (p, $\gamma_1$) cross section values have been obtained from $\gamma_1$ intensities relative to that of the (p, $\gamma_0$) transition. This procedure allowed to remove some possible sources of errors, like the inhomogeneity of the beam and the target material, change of the stoichiometric ratio of $SiO_2$ during evaporation, charge measurement etc.

The present analysis followed closely the method used for $^{28}$Si(p, $\gamma_0$) reaction [1]. The effective potential parameters, selected by requiring to reproduce positions and widths of broad $3/2^-$ and $1/2^-$ resonances, were the same as in Ref. [1]. Then the only parameters allowed to vary in the fitting procedure were the coupling strengths of the incoming proton wave to the GDR mode and the spectroscopic factor of the final state.

The E1 transitions to the first excited state ($3/2^+$) of the $^{29}$P nucleus differ from those to the ground state ($1/2^+$) by the presence of $f_{5/2}$ partial wave in addition to common $p_{3/2}$ and $p_{1/2}$ incoming waves. The experimental total cross section values could be well described using equal coupling strength constants for p and f-waves, however the angular distributions in this case were not satisfactorily reproduced. This analysis yields the value of spectroscopic factor of the first excited state equal to 0.10. Significantly better agreement with the differential cross section values was received, while coupling strength constants of all participating partial waves were allowed to vary independently. A best fit analysis yielded $q_{1/2} = 10 \pm 4$, $q_{3/2} = 20 \pm 4$, $q_{5/2} = 120 \pm 20$, where the parameter $q$ reflecting the coupling strength is defined in the same way as in Ref. [1]. The value of the spectroscopic factor was not significantly affected; the error was estimated to be $\pm 0.05$. Resulting coupling strength constants point to the strong enhancement of the higher partial wave component in the structure of the GDR, which is an effect observed also in the analysis of $^{27}$Al(p, $\gamma$)$^{28}$Si [7] and $^{23}$Na(p, $\gamma$)$^{24}$Mg [8] reactions. The comparison of experimental and theoretical cross section values is presented in Fig. 1.

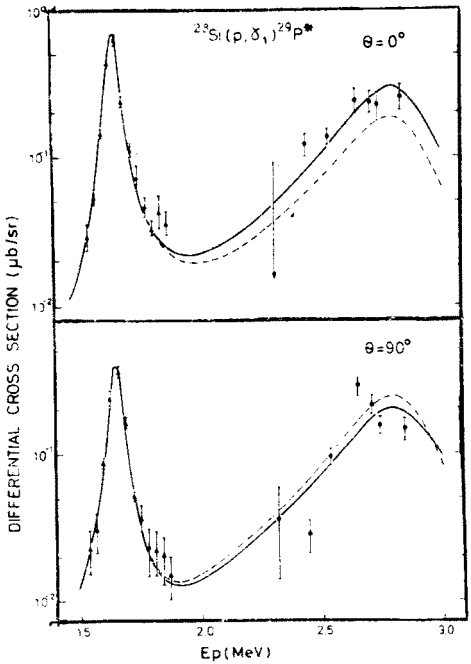


Fig. 1. Comparison of experimental data and model calculations. Experimental differential cross section values for $E_p < 2$ MeV are taken from Ref. [4], the others are from present measurements. The solid line corresponds to the model predictions with strong enhancement of the f-wave coupling to the GDR (best fit), while the dashed one is based on assumption of equal p and f-wave couplings

The method of analyzing radiative proton capture data, which was applied in this work, seems to be well suited also for the extraction of the spectroscopic factor of final states. Generally, capture reactions with radiative exit channel should be more accurate than those reactions, which involve a strongly interacting particle also in the exit channel, like (d, p) or ($^3$He, d). Moreover the application of the effective potential approach [2] incorporating broad resonances into the direct component reduces possible error sources, which could arise from the combined direct plus $R$-matrix analysis scheme, where only the direct component is related to the spectroscopic properties of the final state. However, our result for the first excited state of the $^{29}$P nucleus, $S = 0.10 \pm 0.05$, is much lower than that predicted by shell-model calculations and found in a number of analyses of experimental data (mainly from ($^3$He, d) stripping, see Table I in Ref. [1]), although values as low as 0.21 and 0.23 were also reported. The value of spectroscopic factor obtained in the present analysis suggests, that the structure of the $^{29}$P first excited state is more complicated than predicted so far theoretically. It is worth pointing out, that, in other cases studied within the same model, the resulting spectroscopic factors were consistent with theoretical predictions [1, 9].

The authors wish to thank Z. Wilhelmi for the continuous support of this work. We are indebted to the staff of VdG accelerator for efficient collaboration.

## REFERENCES

[1] T. Matulewicz, P. Decowski, M. Kicińska-Habior, B. Sikora, J. Tōke, *Acta Phys. Pol.* **B14**, 617 (1983).
[2] J. Tōke, T. Matulewicz, *Acta Phys. Pol.* **B14**, 609 (1983).
[3] M. Modirnia, PhD thesis, U. Bordeaux 1978.
[4] F. Terrasi, A. Brondi, P. Cuzzocrea, R. Moro, M. Romano, *Nucl. Phys.* **A324**, 1 (1979).
[5] P. M. Endt, C. van der Leun, *Nucl. Phys.* **A310**, 1 (1978).
[6] C. Rolfs, W. S. Rodney, S. Durrance, H. Winkler, *Nucl. Phys.* **A240**, 221 (1975).
[7] M. Kicińska-Habior, P. Decowski, M. Dąbrowska, W. Grochulski, P. Jaracz, T. Matulewicz, B. Sikora, J. Tōke, E. Somorjai, *Z. Phys.* **A312**, 89 (1983).
[8] M. Kicińska-Habior, M. Dąbrowska, P. Decowski, T. Matulewicz, B. Sikora, J. Tōke, J. Cseh, E. Somorjai, *Z. Phys.* **A318**, 329 (1984).
[9] T. Matulewicz, J. Tōke, *Acta Phys. Pol.* **B15**, 569 (1984).