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RESOLUTION OF THE ^{95}Zr GROUND STATE INTO A DOUBLET

by

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ABSTRACT

The ground state of ^{95}Zr is studied using (d,p) reaction on ^{94}Zr by 15.5 MeV deuterons.

With a resolution in energy of about 13 KeV it was shown that this g.s. is in fact a doublet with a separation of about 23 KeV.

Key-words: Nuclear reactions and scattering involving few-nucleon systems.

INTRODUCTION

While studing the reaction ^{94}Zr (d,d')^{94}Zr at 15.5 MeV using nuclear emulsions as detector[1] the ^{95}Zr ground state peak was located in order to check the consistency of our measurements with the previous results of the reactions ^{94}Zr (d,p)^{95}Zr. Indeed we found the proton peak corresponding to the g.s. of ^{95}Zr at the correct place. However this g.s. was shown up clearly as a doublet. In this paper we show the evidences for the existence of this g.s. doublet. Our resolution in energy was about 13 KeV.

PROCEDURES AND RESULTS

The plates were scanned in 0.2 mm intervals along the plate on Leitz-Ortholux microscopes with 1.25 x 15 x 25 magnification. The distances were measured with an accurate AMES 3223 M clock.

The laboratory energies of the protons in the reaction ^{94}Zr (d,p)^{95}Zr corresponding to the g.s. of ^{95}Zr were calculated at the scattering angles we had: 30°, 34°, 52° and 60°. It's position on the plates was determined for each angle using the computer code "SPECTRE"[2] with the calibration of the magnetic spectrograph from the University of São Paulo where the plates were exposed. These peaks were found at the calculated positions. It is clear from their configurations that they are doublets. The excitation energy of the second level is about 24 KeV.

We could not resolve completelly the two peaks. However, the intensity of both is nearly the same.

If we sum the two peaks and analise as if they where only one we obtain the results shown in Table I together with the ^{94}Zr (d,p) previous results (3) (4)

The intensities of a peak in the several plates were normalized using the counts and the total charge of the deuterons bombarding the target for each plate exposure.

The absolute cross sections were obtained from the normalized counts using the elastic cross section at 60° for ^{94}Zr (d,d') reaction at 15.5 MeV calculeted using distorted-wave code DWUCK[5] and the normalized count of the elastic peak at the same angle and deuteron energy of the same reaction.

Present Work E_d=15.5 MeV					Cohen et al[3] E_d=15 MeV					Bingham et al[4] E_d=33.3 MeV			
Ex (KeV)	ℓ	J^π	$(d\sigma/d\Omega)_{17°}$ (mb/sr)	S	Ex	ℓ	J^π	$(d\sigma/d\Omega)_{17°}$ (mb/sr)	S	Ex	ℓ	J^π	S
0- -0.23	2	$5/2^+$ or $3/2^+$	6.0 or 7.0	0.321±0.005 or 0.567±0.015	0	2	$5/2^+$	5.0	0.30	0	2	$5/2^+$	0.369

Table I - Comparison of ours with previous results for the ground state of ^{95}Zr.

In Table I Ex is the excitation energy, ℓ the angular momentum transfered, J^π the nuclear spin and parity, $(d\sigma/d\Omega)_{17°}$ the cross section at 17° in the angular distribution curve fitting the experimental points and S is the spectroscopic fator. Our S is given by the relation between the measured cross section and the cross section calculated by the distorted wave Born approximation, $\sigma_{exp} = 1.53\ S\ \sigma_{DWBA}$. The factor 1.53 results from the normalization of the deuteron wave function at zero range. Atually our S is the average of those corresponding to the four angles we have. The errors are the standard deviation of the average.

Fig. 1 gives the angular distribution obtained by standard calculations using distorted-wave code DWUCK by Kunz[5]. The parameters of the Wood-Saxon form factor for ^{95}Zr bound state and those of the optical potential for the entrance and exit channels are shown in Table II.

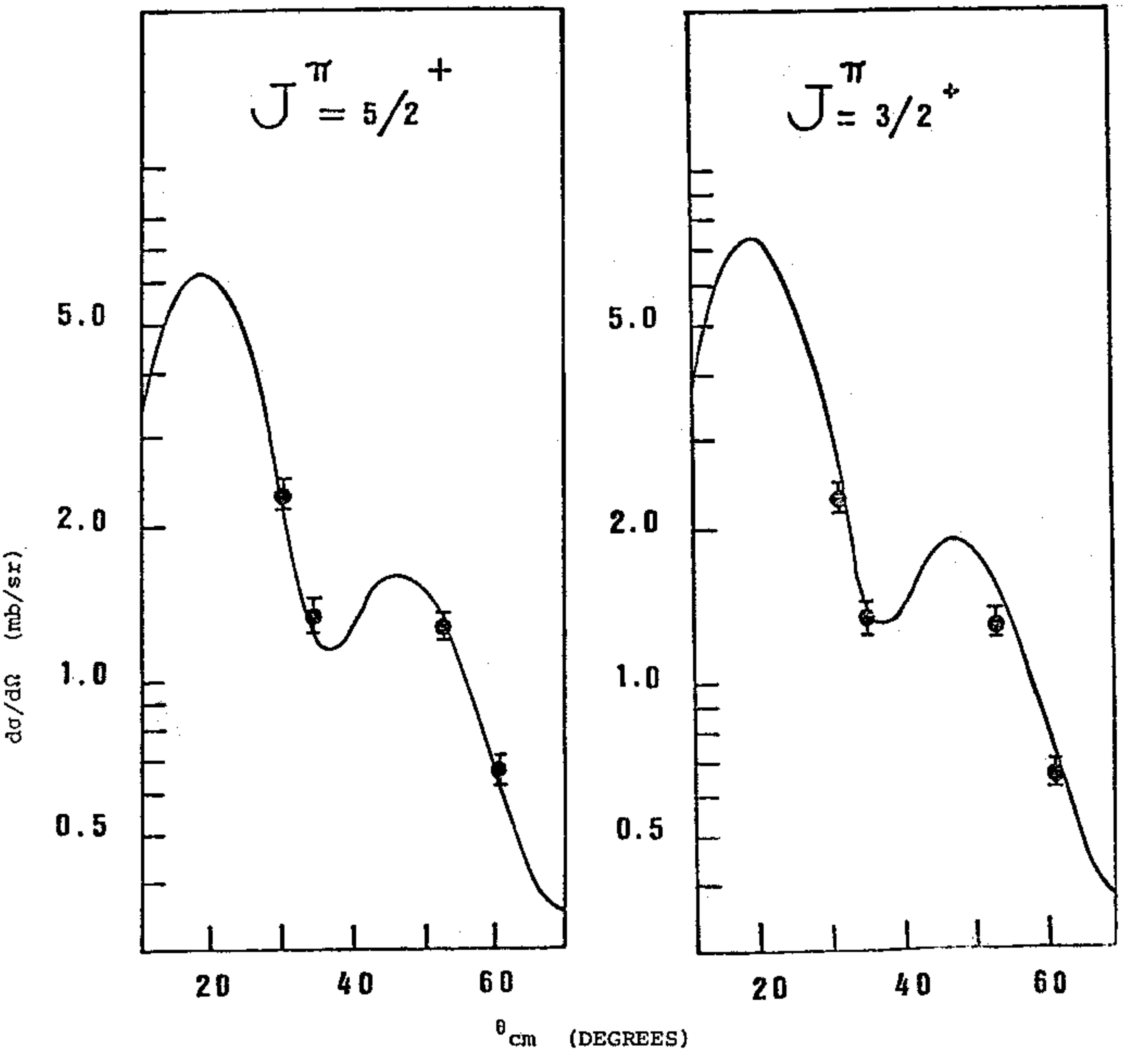

Fig. 1 - Angular distributions. The errors are the statistical and background subtraction ones.

	DEUTERON	BOUND NEUTRON	PROTON
V(MeV)	95.18	(a)	51.60
r_o(fm)	1.15	1.25	1.25
a_o(fm)	0.81	0.65	0.65
w_D(MeV)	18.12		13.5
r_D(fm)	1.34		1.25
a_D(fm)	0.68		0.47
r_C(fm)	1.30		1.25
V_{So}(MeV)	6.53	$\lambda_{so}=25$	7.5
r_{SO}(fm)	1.099	1.14	1.25
a_{SO}(fm)	0.835	0.65	0.47

(a) Adjusted to reproduce the neutron binding energy.

TABLE II - Parameters for $^{94}Zr(d,p)^{95}Zr$ reaction taken from ref. (6).

From Table I and Fig. 1 we see that as expected, the values of ℓ and S agree with previous ones. However our experiment, which has a resolution in energy of about 13 KeV, shows that the g.s. level is resolved into a doublet (with $\sim$23 KeV separation) which was not previously reported. For each level in the doublet the value of J^π may be $3/2^+$ or $5/2^+$ since both values are consistent with the sum of the peaks.

There is no indication of spurious origin for this doublet. Indeed, in the same region where they are we observe three single like proton peaks. They can be reinforced, if we use the sum method(7) (8), summing the spectra over the four angles taking as origin the first single peak. As they are the only reinforced peaks, it is very likely that they are levels resulting from the same (d,p) reaction, the first peak being the g.s. of the resulting nucleus.

The fact that these peaks correspond to the three first levels of the ^{29}Si arising from the $^{28}Si\ (d,p)^{29}Si$ reaction can be shown proceeding as follows. First, we determine the energies of the scattered particle from the positions of the first observed peaks for each angle with the aid of the SPECTRE code(2). The mass M_R of the recoiling nucleus is then calculated by the relation

$$M_R = \frac{2\sqrt{M_d M_p \varepsilon_d}\,(\sqrt{\varepsilon'_p}\cos\Phi' - \sqrt{\varepsilon_p}\cos\Phi)}{\varepsilon'_p - \varepsilon_p} - M_p \qquad (1)$$

which arise from the dynamics of the reaction in the nonrelativistic limit, where M_d and ε_d are the mass and energy of the incoming deuteron,respectively. M_p is the mass of the outgoing proton ε_p and ε'_p being its energies when observed at angle Φ and Φ' from the incident direction, respectively. Then, for exemple, for $\Phi = 30^0$ and $\Phi' = 60^0$ the SPECTRA code (2) gives $\varepsilon_p = 21.499$ MeV and $\varepsilon'_p = 20.839$ MeV respectively. With these values we obtain $M_R \simeq 28.5$ u.m.a. suggesting an A = 29 recoiling nucleus. Indeed the energy of the proton of $^{28}Si\ (d,p)^{29}Si$ which corresponds to the g.s. at 30^0 is 21.472 which agrees with ε_p. Using again the SPECTRA code(2) we obtain the first levels of ^{29}Si shown in Table III.

Present Work Ex (MeV)	P.M. Endt et al[9] Ex (MeV)
0	0
1.282	1.273
2.042	2.032

Table III - The first energy levels of ^{29}Si

Fig. 2 shows the sum spectrum where the single peaks are reinforced. In the same figure we have the doublets formed by the g.s. and first excitation level of ^{95}Zr at the angles indicated. The plates corresponding to 30^0 and 34^0 are not summed in the region 3.10 cm to 2.24 cm and 4.10 cm to 5.30 cm respectively due the presence of carbon contamination. Fig. 3 shows part of the spectrum summed over the four angles taking as origin the g.s. of ^{95}Zr to compare the reinforced doublet with the reinforced single peaks of Fig. 2.

In reference (4) the resolution in energy is about 25 KeV but there is no reference to the possibility of the ^{95}Zr g.s. doublet. This doublet also, does not appear in Hachiro et al paper[10] where γ transitions to the g.s. of ^{95}Zr are determined with $\sim$ 1 KeV resolution. The transition within the doublet may not have been detected due to the energy cut off the detection system. The other transitions to one of the members of a g.s. doublet may not appear by a similar mechanism as in reference (10) where there are no γ transitions to levels very well established in other reactions.

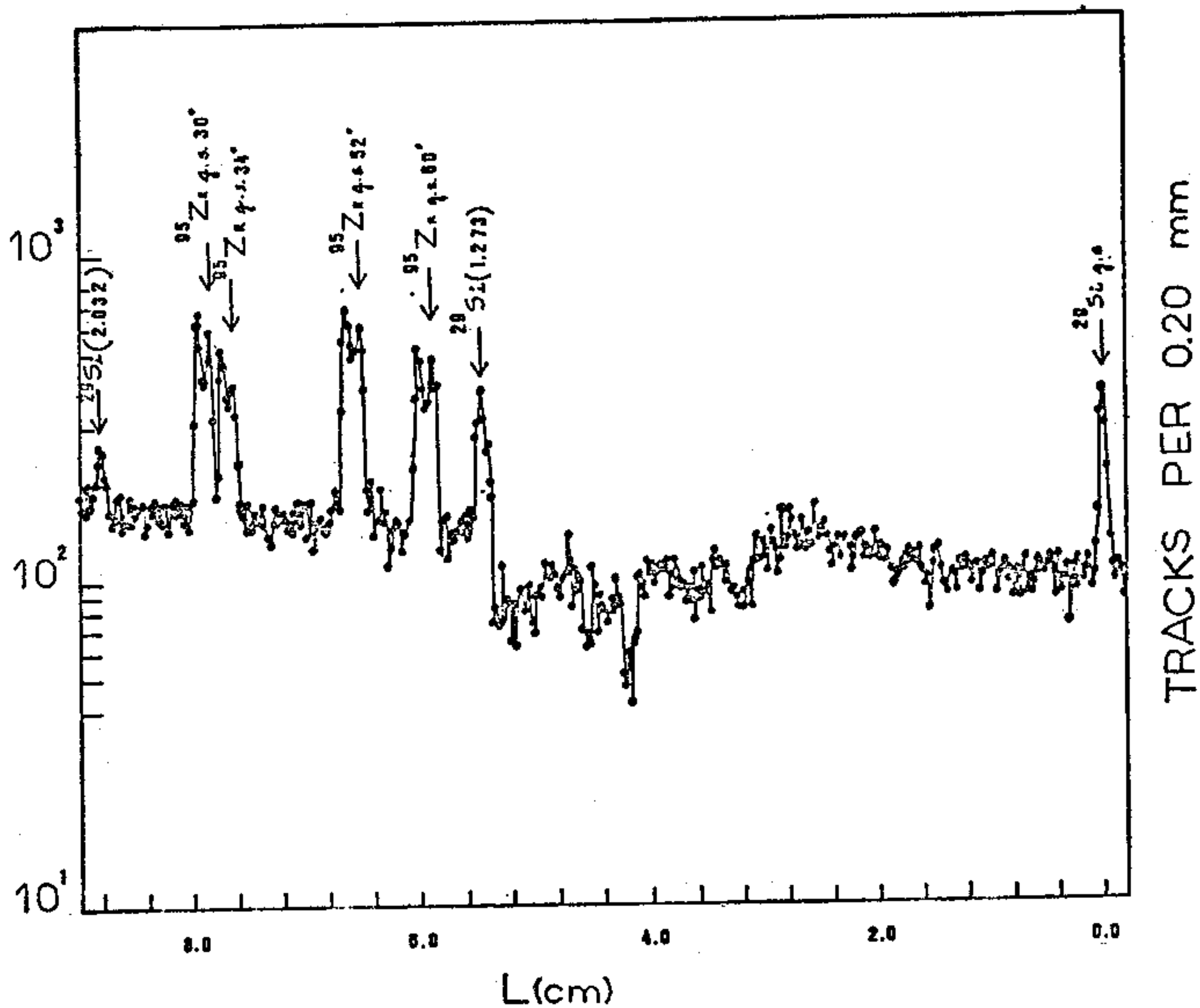

Fig. 2 - Sum spectrum where the single peaks of ^{29}Si are reinforced and the ^{95}Zr g.s. doublets appear in the four angles we have.

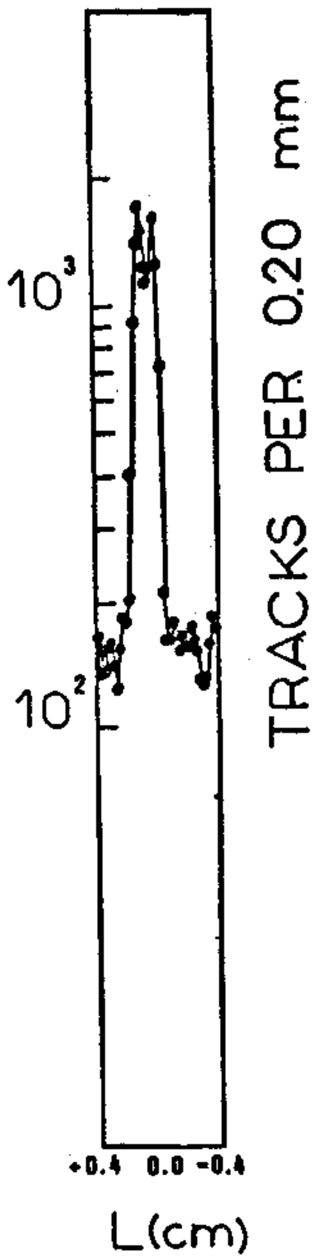

Fig. 3 - Sum spectrum where the doublet from ^{95}Zr is reinforced to be compared with reinforced single peaks from ^{29}Si.

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