High Resolution Study of ^{104}Pd$(d,t)^{103}$Pd

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Information collected in the present high resolution study of ^{104}Pd$(d,t)^{103}$Pd is interpreted within the systematics of the $A\sim100$ region. The paper complements data previously presented by the S.Paulo Group, which were taken with the Pelletron-Enge-Spectrograph facility. A one-to-one correspondence to gamma ray results for ^{103}Pd, collected by the Nuclear Data Sheets (NDS), was achieved and at least four open questions were settled. More reliable spectroscopic strengths were extracted in the present study.

Keywords: $A\sim100$ region; Nuclear structure; Magnetic spectrograph; (d,t) reaction; Spectroscopic factors

I. INTRODUCTION

The (d,t) reaction is a well established spectroscopic tool for assessing neutron-hole strength distributions associated with nuclear states, which can help to disentangle the complex structure of transitional nuclei, in particular, in the $A\sim100$ region. This region has been the object of continuing interest and the S. Paulo Nuclear Spectroscopy with Light Ions Group has put forward some interesting systematics [1], which, besides characterizing some microscopic aspects of the shape transition which occurs around N=59, also revealed a peculiar behavior of some of the yrast states. The Group has been involved in closing some holes in these systematics [2–5], taking advantage of the good beam and focusing properties of the Pelletron-Enge-Spectrograph facilities, since for the given purpose a good energy resolution is essential. The present paper refers to a high resolution study of the ^{104}Pd$(d,t)^{103}$Pd reaction with an incident deuteron energy of 15.0 MeV. Preliminary results based on a partial analysis, have been presented previously [6]. The analysis has been extended to the 14 scattering angles measured and, with respect to the preliminary results based on only 6 angles, more information could be gathered, specially for weakly excited states. Spectroscopic factors associated with twelve of the states observed in the study are here presented for the first time.

II. EXPERIMENTAL PROCEDURE AND ANALYSIS

Due to the characteristics of the Pelletron-Enge-Spectrograph arrangement and to the use of the nuclear emulsion detection technique, resolutions as high as 7-8 keV are attained in (d,t) measurements by the S.Paulo Group [4–6]. The energy resolution achieved in the triton spectra depends on the careful determination of the focal plane of the respective reaction, the use of nuclear emulsion as detectors, on the possibility of producing thin, clean and uniform targets, on the definition of an adequate spectrograph object and on the good resolution of the beam.

The emulsion plates were scanned in strips of 200μm across the plates. Fig.1 shows the triton spectra of the reaction under investigation corresponding to the indicated laboratory scattering angles, which can be regarded as typical of the spectra measured at other angles. The excitation energy region accessible to clean study is, in this reaction, limited to 1.05 MeV by the appearance, on the focal plane, of the elastic peak and its associated tail. The relative normalization of the cross sections was, as usual [2], referred to optical model predictions for the elastic scattering of deuterons on the same target, measured under similar conditions. The detection limit was $\sim 3\text{x}10^{-4} fm^2/sr$.

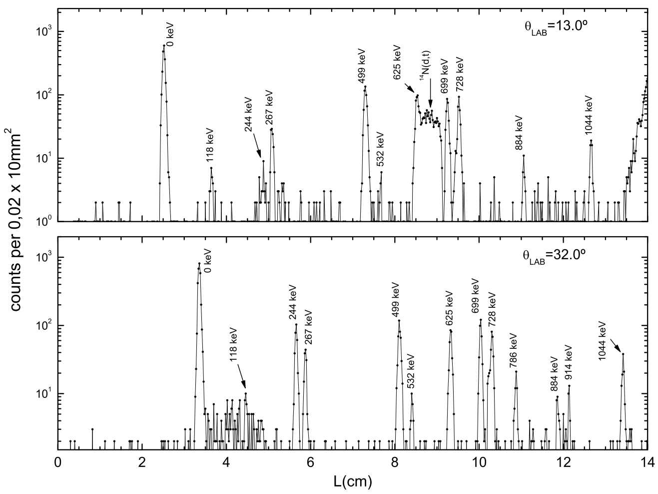

FIG. 1: Triton spectra obtained at 13.0° and 32.0° laboratory scattering angles. The excitation energies attributed to the populated levels are indicated.

Least squares fits of one-neutron pick-up distorted wave Born approximation predictions to the rather well structured experimental angular distributions enable the determination of ℓ transfer and of the corresponding spectroscopic factors of states. Shown in Fig.2 are examples of experimental angular distributions associated with two weakly populated states of interest, besides presenting the improved quality in defining the close doublet $\ell=0+2$ and the low-lying $\ell=4$ transfers.

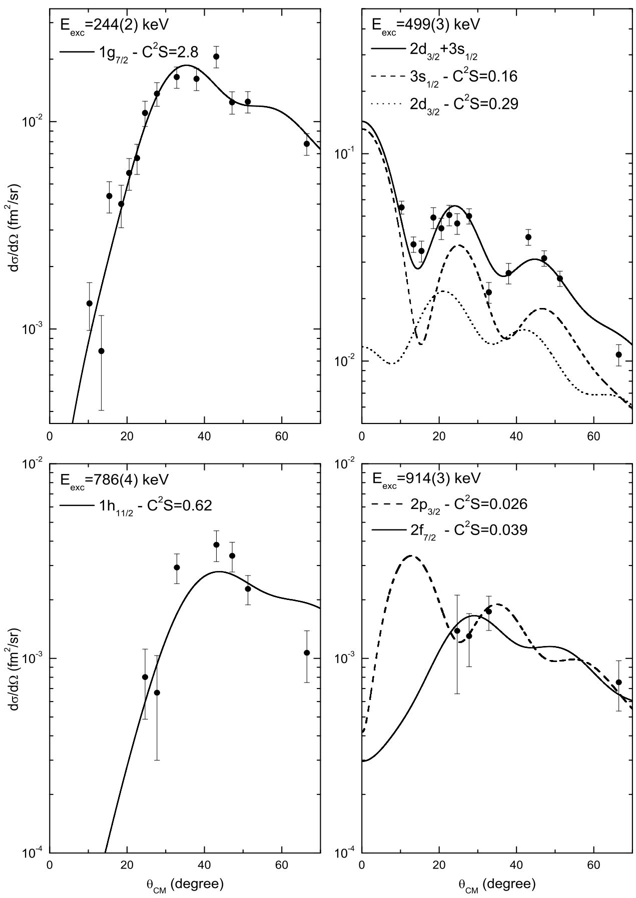

FIG. 2: Experimental angular distributions in comparison with DWBA predictions. Also given are the excitation energies of the populated levels and the corresponding spectroscopic factors.

III. RESULTS AND DISCUSSION

A clear one-to-one correspondence of the 13 nuclear states of ^{103}Pd detected in the present study, below 1.05 MeV, with gamma results [7] was achieved. The former one-neutron pickup work by Scholten et al. [8], was handicapped by a more than eight times worse energy resolution, hampering conclusive comparisons in several instances. An unpublished study by Rickey et al. [9] was therefore taken by the Nuclear Data Sheets (NDS) [7] compilation as reference for the energies. In comparison with the former work [8], both the reduction of the uncertainties in excitation energy, from ΔE =15 keV to ΔE ~1 keV, and the low background settle at least four open questions of the latest NDS [7]. Table 1 presents a summary of the experimental results.

Although being unable, even with the good resolution of the present work, to separate the 4 keV doublet at 500 keV, the angular distribution defines two components, with the correct ℓ values and the corresponding spectroscopic factors could be extracted. Therefore, the level at 499 keV is confirmed as having $J^\pi = 1/2^+$. Also, the conflict between the information obtained by three different reactions and the (d,t) results of Rickey at al. [9] is settled by the observation at forward angles, in very clean spectra, of only a small peak at 532.2 keV, allowing an $\ell > 3$ attribution (see Fig. 1). Therefore, the 535 keV level of the NDS compilation should be eliminated. Furthermore, the 815 keV level, based exclusively on (d,t) results, should also be suppressed, since no sign of such level appears in the spectra of the present study. Finally, also by the forward angle data, there is no possibility of an $\ell = 1$ attribution to the population of the 913.9 keV level, making it an excellent candidate for being the intruder $7/2^-$ state, since similar $\ell = 3$ transfers are seen throughout the region.

Moreover, further new experimental information here gathered fits nicely into the systematics. The first $3/2^+$ state, detected at only 118.8 keV, is weakly populated by (d,t) and (d,p) [7] reactions, as are the $3/2^+$ yrast states present in the $A \sim 100$, for which a $[2d_{5/2}]^3$ main configuration was proposed by the S.Paulo group [3]. The $\ell = 3$ transfer, for which a relationship to the $\ell = 5$ excitations seems clear, since the yrast $11/2^-$ states in the region [1] are followed by a companion $7/2^-$ yrast, was detected in ^{103}Pd at 913.9 keV, lying, consistently with the systematics, 130 keV above the first $11/2^-$ state. Both yrast $3/2^+$ and $(7/2)^-$ levels had not been seen by previous (d,t) studies [8, 9].

TABLE I: Energies, ℓ transfers and spectroscopic strenghts of the present work in comparison with the adopted levels of Nuclear Data Sheets [7].

^{104}Pd$(d,t)^{103}$Pd			^{103}Pd	
Present work			Nuclear data sheets [7]	
Exc. Energy (keV)	ℓ	C^2S	Exc. Energy (keV)	J^π
G.S.	2	1.88	G.S.	$5/2^+$
118.8			118.736 (17)	$3/2^+$
243.8	4	2.8	243.959 (16)	$7/2^+$
267.0	2	0.11	266.861 (17)	$5/2^+$
499.0†	0+2	0.16, 0.29	498.948 (20) 504.24 (7)	$(1/2^+)$ $(3/2^+)$
532.2	> 3		531.972 (22)	$7/2^+$
			535 (5)	$3/2^+,5/2^+$
625.4	2	0.36, 0.29	625.627 (25)	$3/2^+,5/2^+$
699.1	2	0.41	698.746 (22)	$5/2^+$
			718.02 (5)	$9/2^+$
727.8	0	0.16	727.31 (13)	$1/2^+$
785.6	5	0.62	784.79 (10)	$11/2^-$
			815 (2)	$3/2^+,5/2^+$
884.4	(2)	0.052, 0.042	884.67 (5)	$3/2^+,5/2^+$
			900.0 (1)	$9/2^+$
			904.12 (20)	$11/2^+$
913.9	(3)	0.054, 0.039	913.41 (15)	$3/2^-,5/2^-,7/2^-$
1043.8	2	0.15, 0.12	1043.61 (4)	$3/2^+,5/2^+$

†doublet

Improving further with respect to former studies [8, 9], the strongly excited first $7/2^+$ state, which appears at an almost constant excitation energy in the region, had its $\ell = 4$ character well defined by the forward angle data and fits perfectly into the systematics of the N=57 isotones [1].

The spectroscopic factors extracted are presented in Table 1. In comparison with the values published by Scholten et al [8], several diferences are to be discussed. Although both works revealed for the G.S. transition similar spectroscopic strengths, no such consistency is preserved for most of the other excitations. In general, the values of Scholten et al. [8] for the spectroscopic strengths are much higher than those obtained in the present study. This is in line with comments to be found in the published paper [8], where sums exceeding the expected values are reported. In special, even for the strong $\ell = 4$ transfer, the spectroscopic strength reported by Scholten et al. [8] exceeds the value here obtained (see Table I) by more than 60%. The inclusion of this new result into a survey of the experimental information in the region of $A \sim 100$ (always taken from the most recent NDS compilation) [1] strengthens the indications for a peculiar behavior of the yrast $7/2^+$ state. This state occurs in odd nuclei of the region, from Sr to Sn, at almost constant low excitation energy (from 0.2 to 0.4 MeV). Where information is available, the associated spectroscopic strength, gathered through the (d,t) reaction, is also almost constant: 2.3 ± 0.5 (neutrons in the $1g_{7/2}$ orbital), being little affected by the number of neutrons and protons, at least from N=53 to N=63 and from Z=32 to Z=50.

In summary, the much improved energy resolution, high sensitivity and very low background below 1 MeV of excitation, which are, among other factors, due to the emulsion technique, enabled the group to uncover some more of the hidden links in the interesting systematics of the region.

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