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A STUDY OF THE $^{90}\text{Zr}(p,t)^{88}\text{Zr}$ REACTION

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A study of the $^{90}\text{Zr}(p,t)^{88}\text{Zr}$ reaction

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1. Introduction

The investigation of the $^{90}\text{Zr}(p,t)^{88}\text{Zr}$ reaction has been performed to obtain accurate experimental data of differential cross sections. These data are needed for both spectroscopic studies of the nucleus ^{88}Zr and for comparison with the angular distributions obtained in an investigation of the $^{91}\text{Zr}(p,t)^{89}\text{Zr}$ reaction, which has been carried out at the same proton incident energy, in order to study if the two neutrons in the (p,t) reactions are transferred pair-wise from the same orbit or from different orbits.

The level scheme of the ^{88}Zr nucleus has been previously investigated via the β -decay of ^{88m}Nb and ^{88g}Nb [1-3]. Levels of ^{88}Zr have also been investigated via in beam γ -ray spectroscopy using the $^{86}\text{Sr}(\alpha,2n\gamma)^{88}\text{Zr}$ and $^{89}\text{Y}(p,2n\gamma)^{88}\text{Zr}$ reaction [4-6] and the $^{74}\text{Ge}(^{16}\text{O},4n\gamma)^{88}\text{Zr}$ reaction [7].

Furthermore, levels in ^{88}Zr have been studied using the two neutron transfer $^{90}\text{Zr}(p,t)^{88}\text{Zr}$ reaction [9,10] and the α -cluster transfer $^{92}\text{Mo}(d,^6\text{Li})^{88}\text{Zr}$ reaction [8].

2. Experimental procedure and results

A 25 MeV proton beam from the Munich University MP tandem accelerator, bombarded a $50\ \mu\text{g}/\text{cm}^2$ target of ^{90}Zr enriched to about 97%, on a $12\ \mu\text{g}/\text{cm}^2$ carbon backing. Outgoing tritons have been detected in the focal plane of the

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Q3D magnetic spectrometer by the light-ion focal plane detector with periodic readout [11]. Absolute cross sections, calculated using the target thickness, solid angle and collected charge, are estimated with an uncertainty of $\pm 15\%$. Areas and centroids of the triton peaks have been determined with the code AUTOFIT [12]. The energy calibration was carried out by means of a third order polynomial fit to the position spectrum, using the following peaks from ref. [13]: 1.818, 2.140, 2.456, 2.539, 2.605, 2.888 and 3.033 MeV. The estimated energy accuracy is ± 3 keV.

In Table I the energies of the levels of ^{88}Zr measured in the present work, and the attributed spins and parities are given together with the energies, spins and parities of ^{88}Zr levels adopted so far [13] and with the energies, spins and parities of the levels observed in previous (p,t) reactions [8,9].

Table I: ^{88}Zr Levels

<i>Present work</i>		<i>(p, t) reaction [8]</i>		<i>(p, t) reaction [9]</i>		<i>Adopted levels [13]</i>	
E_x	J^π	E_x	J^π	E_x	J^π	E_x	J^π
0	0 ⁺	0	0 ⁺	0	0 ⁺	0	0 ⁺
1.057	2 ⁺	1.055	2 ⁺	1.057	2 ⁺	1.057	2 ⁺
1.521	0 ⁺	1.520	0 ⁺	1.517	0 ⁺	1.521	0 ⁺
1.818	(2 ⁺)	1.820	(2 ⁺ , 4 ⁺)	1.816		1.818	(2 ⁺)
2.140	4 ⁺	2.130	4 ⁺	2.134	4 ⁺	2.140	4 ⁺
2.225	0 ⁺	2.225	0 ⁺	2.225	0 ⁺	2.225	0 ⁺
2.456	3 ⁻	2.445	3 ⁻	2.446	3 ⁻	2.456	3 ⁻
2.539	5 ⁻	2.52	(4 ⁺)			2.539	(5 ⁻)
2.570	2 ⁺	2.57	2 ⁺			2.570	2 ⁺
2.605	4 ⁺	2.60	(4 ⁺ , 6 ⁺)			2.605	(4 ⁺)
						2.674	
2.801	5 ⁻	2.795	5 ⁻	2.793	5 ⁻	2.801	5 ⁻
2.811	6 ⁺					2.811	(6 ⁺)
2.888	(2 ⁺)	2.89	(4, 6, 8)	2.875	(8 ⁺ , 6 ⁺)	2.888	(8 ⁺)
2.928	3 ⁻						
2.990	5 ⁻					2.990	(3 ⁻ , 4 ⁻ , 5 ⁻)
						2.998	
3.027	2 ⁺						
3.033	3 ⁻	3.02	2 ⁺ , (4 ⁺)			3.033	(3, 4 ⁺)
		3.06	(4 ⁺)			3.060	(4 ⁺)
3.092	5 ⁻						

Since only natural-parity states are allowed in the one-step (p,t) reaction process (assuming that the transferred neutron pair is in a S=0 configuration), each final level excited by pick-up of a neutron pair from the even-even target ^{90}Zr ($J^\pi=0^+$), will be populated with a unique L-transfer. Assignment of L-transfer values then yields directly spin-parity assignments for the observed states in ^{88}Zr .

As shown in Fig.s~1 and 2, the fit to the experimental data is rather good.

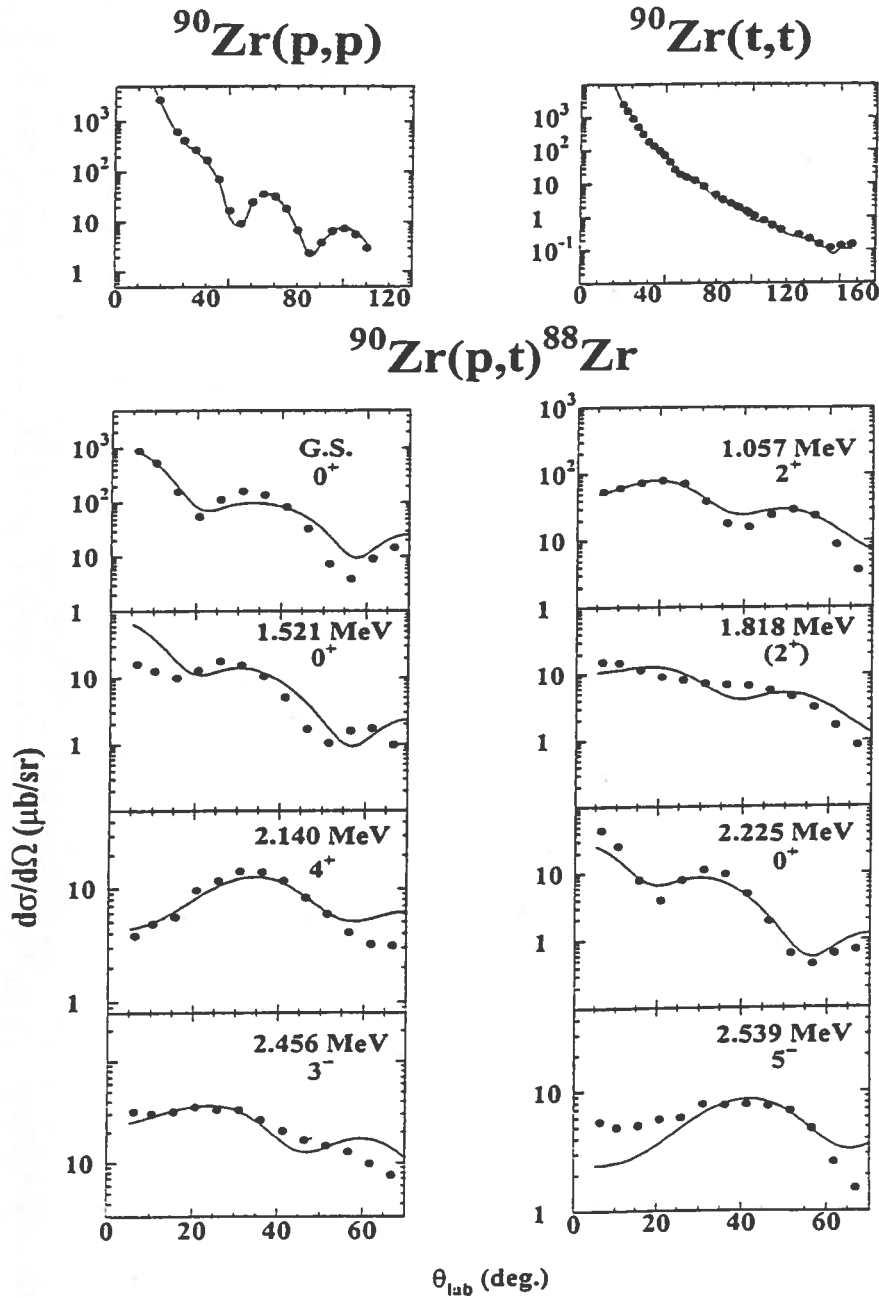


Figure 1: The upper part reports the results of the fitting procedure with respect to the elastic scattering data, for the entrance and exit channels. The lower part shows the angular distributions for ^{88}Zr levels up to excitation energy of about 3.1 MeV, compared with the calculations performed using Double-Folded triton potentials.

$^{90}\text{Zr}(p,t)^{88}\text{Zr}$

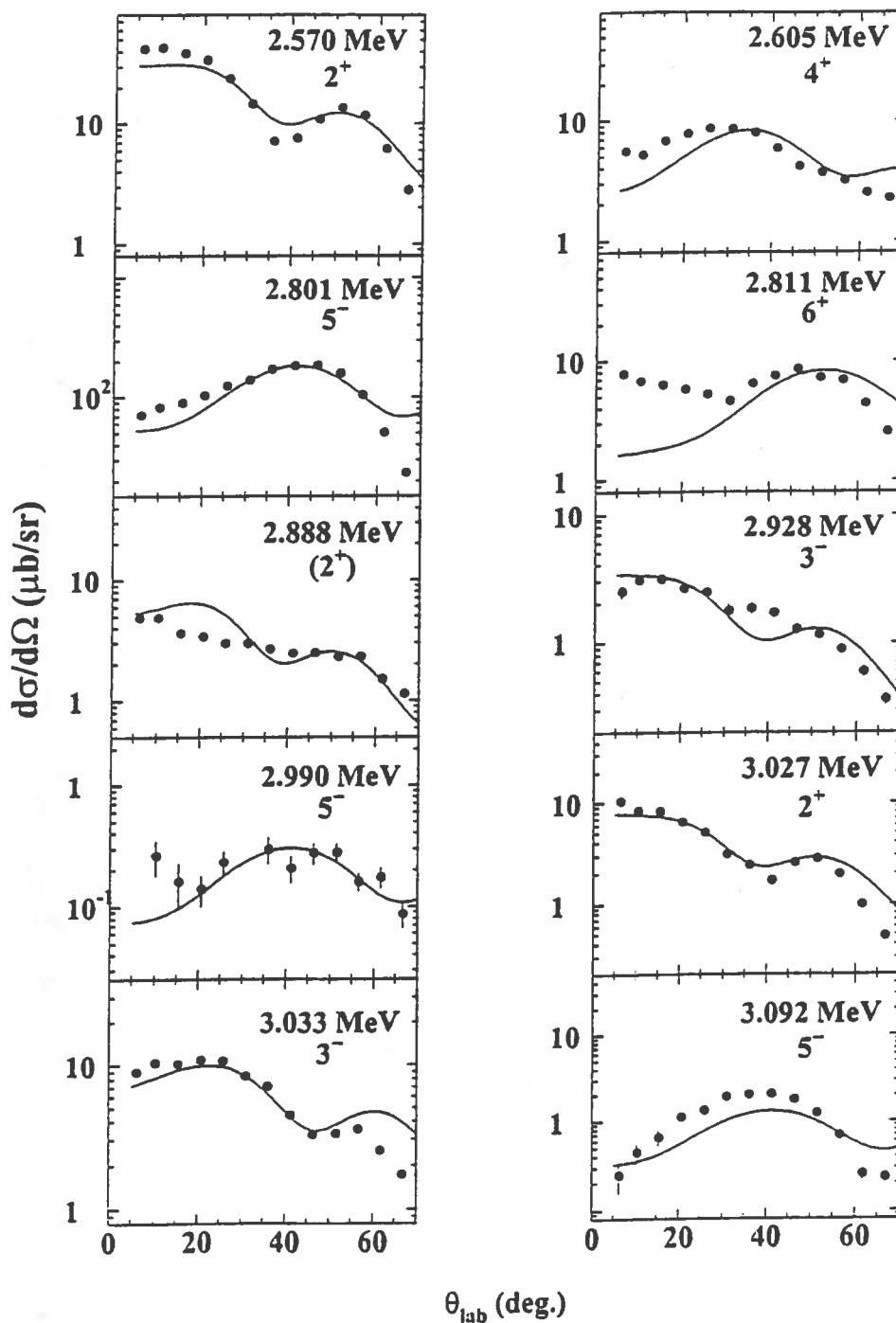


Figure 2: Angular distributions for ^{88}Zr levels up to the 3.092 MeV state, compared with the calculations carried-out using Double-Folded triton potential.

The $L=0$ DWBA calculations for the G.S. and for the 2.225 MeV level and $L=2$ for levels at 1.057 MeV, 2.570 MeV and 3.027 MeV particularly well reproduce the experimental data. On the other hand the $L=2$ theoretical curve

reproduces the mean slope of the measured angular distribution for the 1.818 MeV and 2.888 MeV levels.

The levels at 2.140 and 2.605 MeV are well described by the L=4 transfer. The main maximum of the angular distribution for the level at 2.811 MeV is reproduced by the L=6 transfer, while the part at forward angles systematically deviates from the experimental values.

For the negative-parity states, the levels at 2.456, 2.928 and 3.033 MeV are quite well reproduced by L=3 transfer and the levels at 2.539, 2.801 and 3.092 MeV by the L=5 transfer.

4. Shell model calculations

In connection with the experimental work here presented, we will add some preliminary theoretical predictions of the energy spectrum in the framework of shell model, using the OXBASH code [23].

For the calculations, the shell model Hamiltonian can be written as

$$H = \sum_i \varepsilon_i a_i^\dagger a_i + \sum_{ijkl} V_{ijkl} a_i^\dagger a_j^\dagger a_k a_l$$

For calculating the two body matrix elements V_{ijkl} , the PMM90 interaction [23], which was introduced by B. A. Brown, is used, while the model space has been constructed from the $1f_{5/2}$, $2p_{3/2}$, $2p_{1/2}$ and $1g_{9/2}$ orbitals for both neutrons and protons.

The allowed occupation numbers, in square brackets, for each orbital and the corresponding total single particle energies ε_i (MeV) used to generate both positive (PPS) and negative (NPS) parity states are given in the following:

PPS: $1f_{5/2}$ [10-12] 2.30 MeV, $2p_{3/2}$ [6-8] 3.40 MeV, $2p_{1/2}$ [2-4] 5.13 MeV, $1g_{9/2}$ [8-10] 2.75 MeV;

NPS: $1f_{5/2}$ [12] 2.30 MeV, $2p_{3/2}$ [7-8] 3.40 MeV, $2p_{1/2}$ [2-4] 5.13 MeV, $1g_{9/2}$ [9-11] 2.75 MeV.

The calculated level energies are compared in Fig.3 with the corresponding experimental ones seen in the present experiment. For positive parity states the number of predicted states is correct and the calculated energies are in acceptable agreement with the experiment. Yet, the 2^+ states are systematically predicted at higher energies and the 4^+ and 6^+ at lower energies than in experiment. A similar agreement is found for the negative parity states, with the exception of the first 5^- state, predicted at 1.497 MeV of excitation energy and not seen experimentally.

The main components of the positive and negative parity states are given in the Tables III and IV. Note that, for the lowest 0^+ , 2^+ , 4^+ and 6^+ , the main component always corresponds to having a full shell closure at Z, N=40 and the

remaining 8 neutrons in the $g_{9/2}$ shell. Nevertheless, the part of wave functions corresponding to two particle core excitation across $N=40$ subclosure is rather large and amounts to about 41%, 53%, 44% and 41%, respectively.

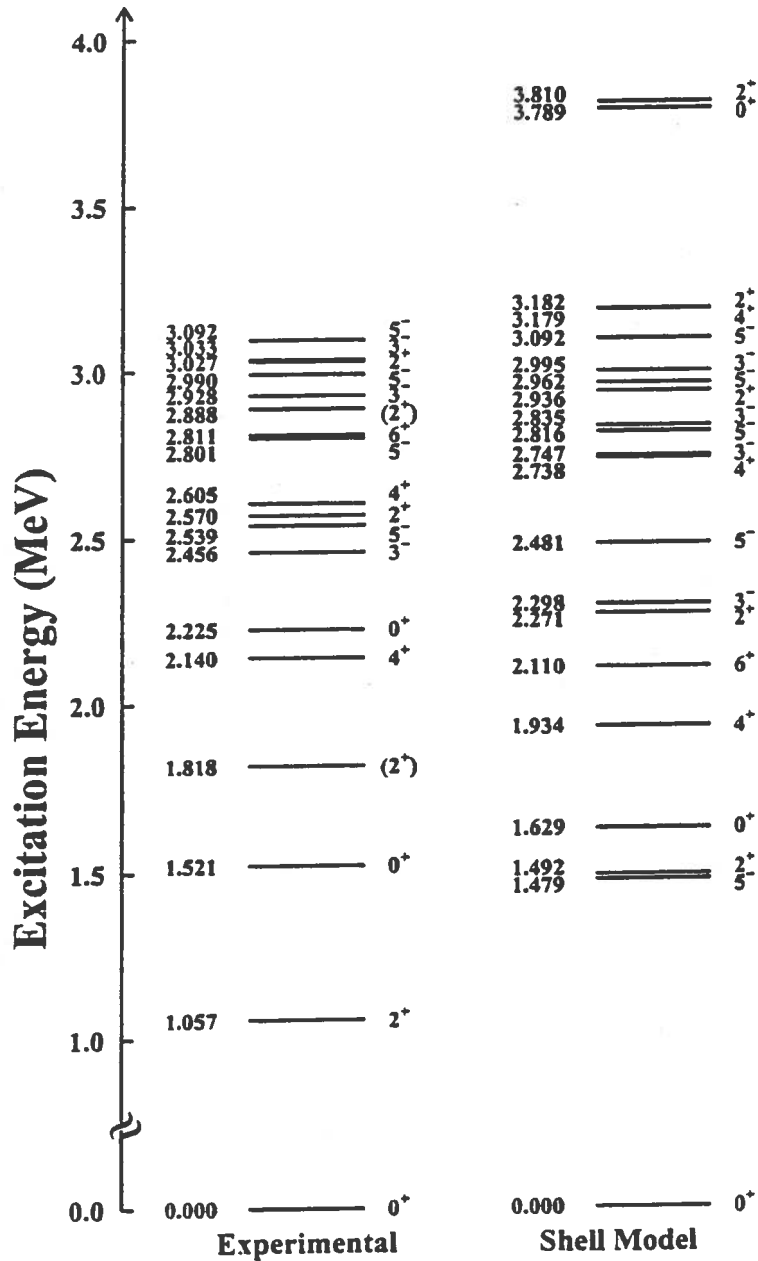


Figure 3: Energy level scheme comparing experimental and shell model results.

Table III: The wave functions of the first 0^+ , 2^+ , 4^+ , and 6^+ states of ^{88}Zr . Each line corresponds to a state of the basis, which partition order is reported in the last four columns. [NO] is the number of unpaired nucleons; p% is the percent occupation contributing more than 0.5%

E(th), J^π	0.000, 0^+	1.492, 2^+	1.934, 4^+	2.110, 6^+	Orbit partition order				
	[NO]	p%	p%	p%	$f_{5/2}$	$p_{3/2}$	$p_{1/2}$	$g_{9/2}$	
[2]		1.50	1.66	1.88	1.82	11	7	4	10
[0]		16.90	14.94	13.93	13.46	10	8	4	10
[2]		2.05	3.98	2.68	2.44	11	8	3	10
[2]		1.94	4.09	3.00	2.72	12	7	3	10
[0]		7.36	8.35	7.71	7.37	12	6	4	10
[0]		11.92	19.58	15.45	13.19	12	8	2	10
[0]		58.32	47.41	55.34	59.01	12	8	4	8

Table IV: The wave functions of the first 3^- and 5^- states of ^{88}Zr . Each line corresponds to a state of the basis, which partition order is reported in the last four columns. [NO] is the number of unpaired nucleons; p% is the percent occupation contributing more than 0.5%

E(th), J^π	2.298, 3^-	1.479, 5^-	Orbit partition order				
	[NO]	p%	p%	$f_{5/2}$	$p_{3/2}$	$p_{1/2}$	$g_{9/2}$
[2]		13.74	2.27	12	7	2	11
[2]		27.85	3.93	12	7	4	9
[2]		58.41	93.80	12	8	3	9

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