ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Milano

INFN/BE-95/04
23 Novembre 1995

P. Guazzoni, U. Atzrott, G. Cata-Danil, G. Graw, J. Gu, R. Hertenberger, M. Jaskola, P. Schiemenz, G. Staudt, A. Vitturi, L. Zetta:

($\vec{p}$, α) REACTIONS ON ODD-MASS TARGET NUCLEI

Contribution selected for oral presentation at INPC95, International Nuclear Physics Conference, August 21-26 1995, Beijing, China

SIS-Pubblicazioni
dei Laboratori Nazionali di Frascati

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Milano

P.Guazzoni, U. Atzrott, G. Cata-Danil, G.Graw, J.Gu, R.Hertenberger, M.Jaskola, P.Schiemenz, G.Staudt, A.Vitturi and L.Zetta

$(\vec{p}, \alpha)$ REACTIONS ON ODD-MASS TARGET NUCLEI

Contribution selected for oral presentation at INPC95,
International Nuclear Physics Conference, August 21-26, 1995 Beijing

SIS - Pubblicazioni
dei Laboratori Nazionali di Frascati

$(\vec{p}, \alpha)$ REACTIONS ON ODD-MASS TARGET NUCLEI

P.Guazzoni[a], U. Atzrott[b], G. Cata-Danil[a,c], G.Graw[d], J.Gu[e,f], R.Hertenberger[d], M.Jaskola[a,g], P.Schiemenz[d], G.Staudt[b], B. Valnion[d], A.Vitturi[e] and L.Zetta[a]
[a]*Dipartimento di Fisica dell'Università and I.N.F.N., I-20133 Milano, Italy*
[b]*Physikalisches Institut, Universität Tübingen, D-72076 Tübingen, Germany*
[c]permanent address:*Institutul de Fizica Atomica, Bucarest, Romania*
[d]*Sektion Physik der Universität München, D-85748 Garching, Germany*
[e]*Dipartimento di Fisica dell'Università and I.N.F.N., I-35131 Padova, Italy*
[f]permanent address:*Institute of Modern Physics, Academia Sinica, Lanzhou, China*
[g]permanent address:*Soltan Institute of Nuclear Studies, Swierk, Poland*

Abstract

This contribution presents high resolution results for two $(\vec{p}, \alpha)$ reactions on odd target nuclei, ^{209}Bi and ^{91}Zr. Also if DWBA calculations, using both Woods-Saxon and Double-Folded potentials for α-particles, have been done, only two kind of analysis are presented here:

a) spins and parities have been attributed to the observed multiplets of excited states in the residual nuclei ^{206}Pb and ^{88}Y, using the homology concept;

b) shell model calculations have been performed for the homologous states, using the OXBASH code.

In low resolution (1) and afterward in high resolution experiments (2,3,4,5) at 22 MeV performed with the Munich Tandem, polarized source, Q3D and position and angle resolving light ion detector, it has been shown that spectra of α-particles emitted in proton induced reactions on target nuclei having one unpaired nucleon outside a magic shell, display distinctive features which indicate that this last, slightly bound, nucleon may act as spectator in the process. In fact in case of weak coupling between the parent state and the spectator nucleon, it is expected for the son states of the excited multiplets that:

a) both angular distributions of cross section and asymmetry for transitions to homologous states to be very similar in shape;

b) the differential cross section for population of a parent state to be of the same magnitude of the sum of the cross sections of the transitions to the multiplet of son states which corresponds to a given parent state;

c) the ratio between the son and the parent state cross sections for the population of a state of spin J, in a given multiplet, to be proportional to (2J+1).

The aim of the present contribution is to show, for the first time together, the most meaningfull experimental results achieved and some preliminary shell model calculations done with the OXBASH code (6), which seem to confirm the spectator role of the unpaired nucleon for transitions to homologous levels and the concept of homology as spectroscopic tool to identify spin and parity of a large number of levels with relatively high excitation energy.

In fig.s 1,2 are shown the cumulative cross sections and analyzing powers for transitions to different multiplets of ^{206}Pb and ^{88}Y compared with the cross sections and analyzing powers for transitions to the corresponding parent states. In the case of ^{88}Y the cumulative cross sections include the contributions of the transitions to fragmented levels(5).

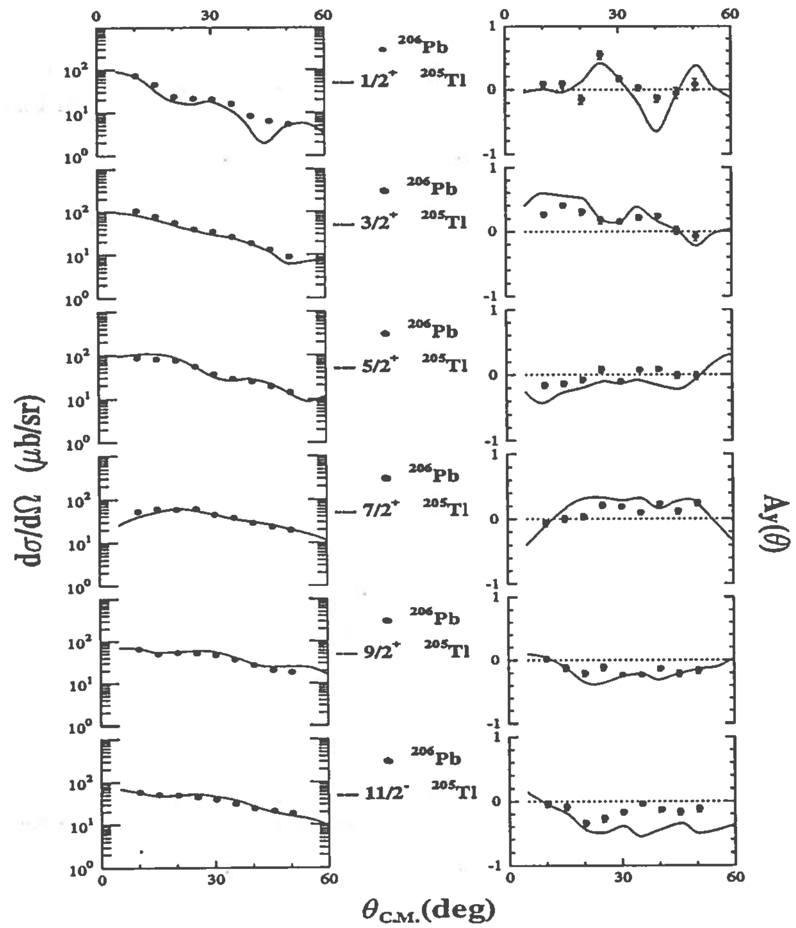

Fig. 1: Cumulative cross sections and analysing powers for transitions to different multiplets of ^{206}Pb (dots) compared with the experimental cross sections and analysing powers for transitions to the corresponding ^{205}Tl parent states (solid lines)

In fig.s 3,4 experimental energy spectra for ^{206}Pb and ^{88}Y homologous levels, arising from the coupling of the spectator nucleon with the states excited in the parent nucleus, ^{205}Tl and ^{87}Y respectively, are compared with theoretical ones, obtained with the OXBASH code.

For some levels of ^{88}Y, belonging to different multiplets, only the parity is assigned, due to the fact that the shape of the differential cross section and asymmetry for each of these levels fits very well the corresponding one of the respective parent state and if the contribution of these levels is included in the cumulative cross section of the proper multiplet, the parent state angular distribution of cross section and asymmetry is quite well reproduced.

Tables I and II show spin and parity attributions for homologous levels of ^{206}Pb and ^{88}Y, compared with the adopted ones. The presented results arise both from analysis of the experimental data exploiting the homology with low energy states ^{205}Tl and ^{87}Y and from shell model calculations.

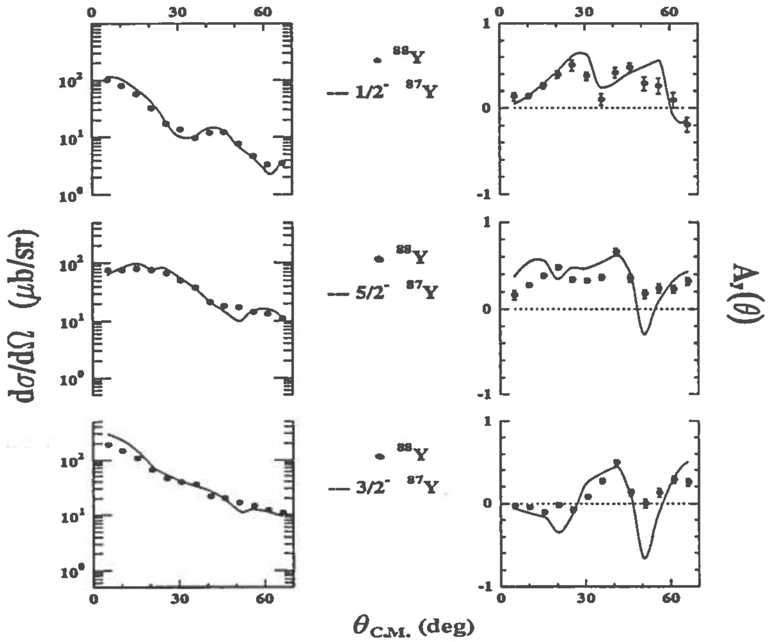

Fig. 2: The same as in fig. 1 for ^{88}Y and ^{87}Y

TABLE I

^{205}Tl		^{206}Pb			
E_{exp}	J^π	E_{exp}	E_{shell}	J^π	J^π_{ad}
g.s.	$\frac{1}{2}^+$	3.273	3.38	5^-	5^-
		3.672	3.35	4^-	
0.204	$\frac{3}{2}^+$	3.237	3.84	4^-	4^-
		3.399	3.57	5^-	5^-
		3.653	3.81	6^-	
		3.716	3.73	3^-	3^-
0.619	$\frac{5}{2}^+$	3.828	(4.59,4.36)	$(6,7)^-$	
		3.980	4.65	2^-	
		3.994	4.27	5^-	
		4.044	(4.38,4.26)	$(3,4)^-$	
		4.120	(4.59,4.36)	$(6,7)^-$	
		4.221	(4.38,4.26)	$(3,4)^-$	
0.924	$\frac{7}{2}^+$	4.243	4.87	$(8)^-$	
		4.257	4.51	$(5)^-$	
		4.317	4.56	2^-	
		4.373	(4.63+4.49)	(3^-+7^-)	
		4.532	(4.55+4.59)	(4^-+6^-)	
1.430	$\frac{9}{2}^+$	4.584	4.49	7^-	
		4.673	5.1	8^-	
		4.687	5.05	2^-	
		4.728	5.4	9^-	
		4.833	4.5	5^-	
		4.862		3^-	
		4.878		6^-	
1.484	$\frac{11}{2}^-$	4.818	5.07	10^+	
		4.912	5.07	4^+	(3^-)
		4.925	4.98	5^+	
		4.941	4.89	7^+	(6^+)
		5.011	4.91	9^+	
		5.078	5.20	3^+	
		5.112	4.92	6^+	(4^+)
		5.149	4.87	8^+	(8^+)
			5.66	2^+	

TABLE II

^{87}Y		^{88}Y			
E_{exp}	J^π	E_{exp}	E_{shell}	J^π	J^π_{ad}
g.s.	$\frac{1}{2}^-$	2.293	2.181	2^-	
		2.444	2.158	3^-	(10^+)
0.794	$\frac{5}{2}^-$	2.734	2.673	3^-	$3^+,4^+,5^+$
		2.764	2.703	2^-	
		2.787	3.041	1^-	
		2.830	2.645	4^-	
		3.145		$-$	
			3.117	0^-	
		3.208		$-$	
			3.133	5^-	
0.982	$\frac{3}{2}^-$	2.944	3.086	2^-	
		2.997		$-$	
		3.025		$-$	
		3.052		$-$	
		3.093	2.990	3^-	
		3.122	3.523	1^-	

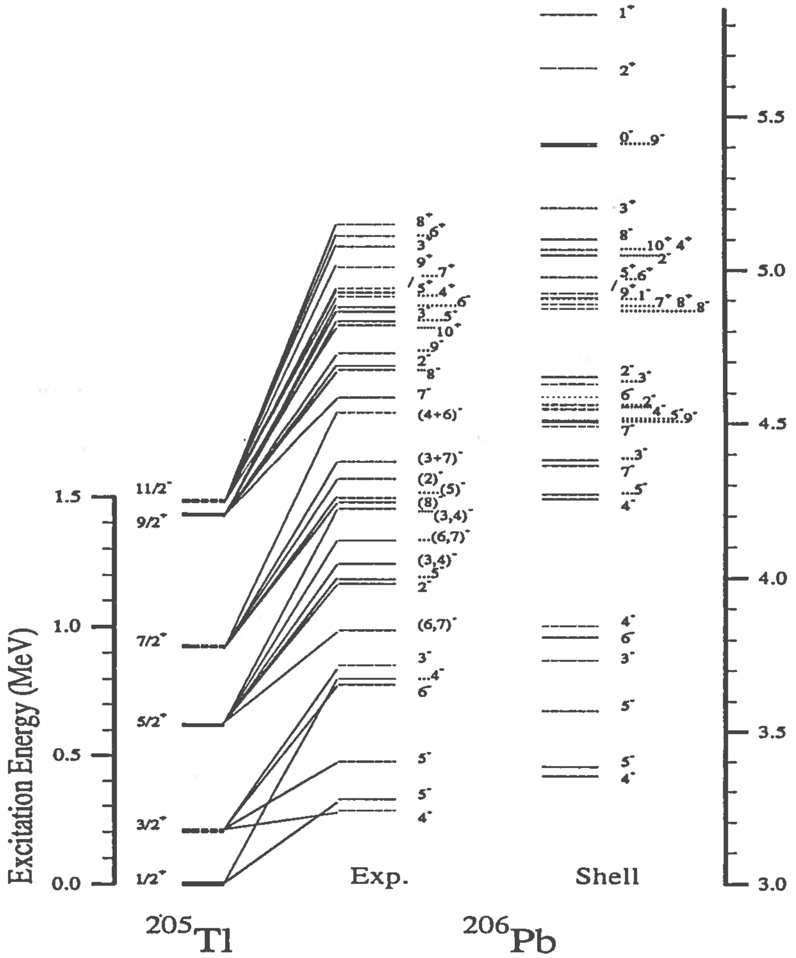

Fig. 3: Comparison of experimental and theoretical energy spectra for ^{206}Pb. Solid and dashed lines identify homologous levels in ^{205}Tl and ^{206}Pb.

Shell model calculations have been performed in both the pair of residual nuclei ^{206}Pb, ^{205}Tl and ^{88}Y, ^{87}Y, based on the usual two-body Hamiltonian

$$H = \sum_i \epsilon_i a_i^\dagger a_i + \sum_{i>j=1,k>l=1} V_{ijkl} a_i^\dagger a_j^\dagger a_k a_l$$

and using the code OXBASH.

For the calculations regarding the pair ^{206}Pb, ^{205}Tl the core has been assumed to be ^{208}Pb and ϵ_i are the single-hole energies of proton (neutron)-hole nucleus ^{207}Tl (^{207}Pb), and the single-particle energies of neutron-particle nucleus ^{209}Pb.

Single Particle Orbitals (S.P.O.) and Single Particle Energies (S.P.E.) used in the calculations, for protons and neutrons, are shown in the following.

proton	S.P.O.	$1g_{7/2}$	$2d_{5/2}$	$2d_{3/2}$	$3s_{1/2}$	$1h_{11/2}$		
	S.P.E.	11.483	9.696	8.364	8.013	9.361		
neutron	S.P.O.	$1i_{11/2}$	$2g_{9/2}$	$2g_{7/2}$	$3d_{5/2}$	$3d_{3/2}$	$4s_{1/2}$	$1j_{15/2}$
	S.P.E.	-3.158	-3.937	-1.446	-2.370	-1.400	-1.905	-2.514

The two-body matrix elements

$$V_{ijkl} = \langle ij\,|V|\,kl\rangle$$

have been calculated from MSDI (Modified Surface Delta Interaction).

The configuration space has been assumed of the form $(3h)$ for ^{205}Tl, i.e.

$$|\,\pi j_1^{-1}, \nu(j_2^{-1}, j_3^{-1})_{J'}, J >$$

and a mixing of $(2h)$ and $(3h-1p)$ for ^{206}Pb, i.e.

$$|\,\nu(j_1^{-1}, j_2^{-1}), J >$$

and

$$|\,\pi(j_1^{-1}, h_{9/2}, J')\nu(j_2^{-1}, j_3^{-1}), J''), J >$$

with a proton particle in the $h_{9/2}$ shell.

About the nature of the states in ^{205}Tl the $1/2^+$ and $3/2^+$ states display a predominant single-hole proton character, the total probability of having a hole in the $s_{1/2}$ and in the $d_{3/2}$ orbital respectively, being in both cases larger than 70% . This is not the case of $5/2^+$ and $7/2^+$ states. For the $5/2^+$, for example, the percentage of $d_{5/2}$ single-hole only amounts to approximately 10%, the main component still being the $s_{1/2}$ hole ($\sim$67%) with recoupling of the neutron holes to non-zero angular momentum.

In spite of the large configuration mixing, multiplets can be sorted out in the ^{206}Pb spectrum, which can be put in connection with parent states in ^{205}Tl, with spectator role

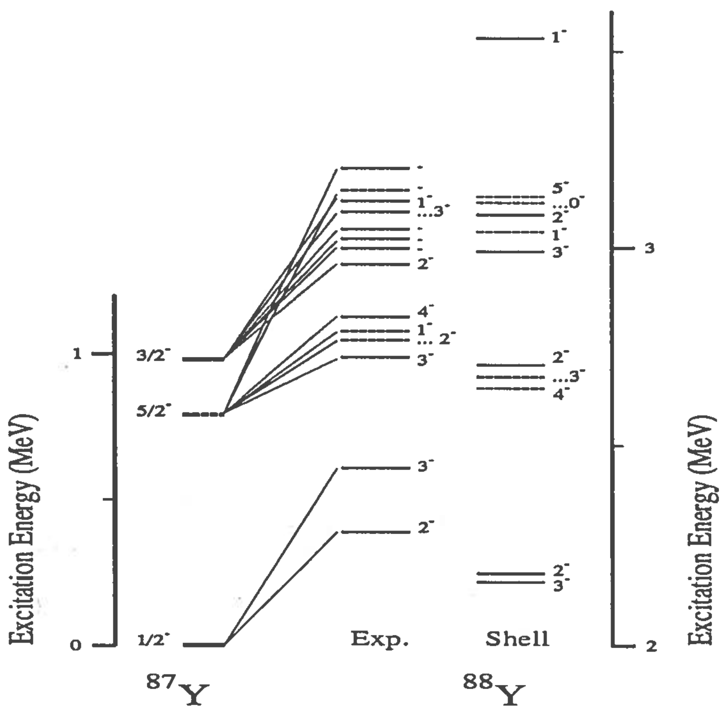

Fig. 4: The same as in fig.3 for ^{88}Y and ^{87}Y. Conventions are the same as in fig. 3

of the $h_{9/2}$ proton orbital. In most cases the states of each multiplet display wave functions which are very similar among them, and, more important, similar to the wave function of the parent state in ^{205}Tl. And this is not only the case of the multiplets homologous to the *rather pure* $1/2^+$ and $3/2^+$ states, but also in the case of the largely mixed $5/2^+$ and $7/2^+$.

The situation is even clearer in the case of the positive-parity multiplet 1^+,...,10^+. The $11/2^-$ state is a rather pure $h_{11/2}$ hole state, with a total content of $h_{11/2}$ of the order of 90%. All states of the multiplet display practically the same structure, therefore giving strong support of considering the multiplet as homologous of the $h^{-1}_{11/2}$state, coupled to the $h_{9/2}$ particle.

A last comment deserve the centroids and the spreadings of the different multiplets. These are in acceptable overall agreement with the experimental findings, even if the sequence of different multipolarities is not always fulfilled.

A particular problem arises with the $4^-, 5^-$ doublet, which is acceptably reproduced as energies, but is assigned by the calculations as the $1/2^+ \otimes h_{9/2^-}$ configuration. the analysis of the $(\vec{p}, \alpha)$ reaction, instead, indicates the lowest 4^- state as belonging to the $3/2^+ \otimes h_{9/2^-}$ multiplet. Such a discrepancy calls, from one side, for an improvement of the residual interaction beyond the MSDI, and for an extension of the model space with the inclusion of neutron core-excitations , leading to $4h - 2p$ configuration.

We will illustrate now the shell model calculations for ^{88}Y levels. It is well known that the structure of nuclei in the region $A \approx 90$ ($Z \approx 40$, $N \approx 50$) is rather complex. In particular the possible existence of a proton subshell (at $Z = 38$ or 40) and the role of the intruder orbital $g_{9/2}$ has been lengthily debated. The case of ^{88}Y falls into this wide problematics. Since our attention was particularly concentrated to possible evidence of levels in ^{88}Y homologous to states in ^{87}Y, the calculations have been parallelly performed for both ^{87}Y and ^{88}Y nuclei.

We have used to construct the model space the orbitals and the single-particle energies ϵ_i given in the following:

	proton				neutron				
S.P.O.	$1f_{5/2}$	$2p_{3/2}$	$2p_{1/2}$	$1g_{9/2}$	$1g_{9/2}$	$1g_{7/2}$	$2d_{5/2}$	$2d_{3/2}$	$3s_{1/2}$
S.P.E.	-8.90	-12.62	-9.61	-5.80	0.66	6.00	4.22	7.22	5.03

For the two-body matrix elements V_{ijkl} we have used the set GWBXC (7), which are essentially G-matrix effective interactions based on realistic Paris potential.

It is important to point out the effect of the configuration mixing, from one side, and of the nature of the residual interaction, from the other.

In fact the predicted levels when pure configurations are assumed, namely when only the diagonal part of the residual interaction is included, give a correct ordering and position for the states 4^--5^- (not homologous and corresponding to the pure configuration $\pi(p_{1/2})^{-1}\nu(g_{9/2})^{-1}$), and for multiplets of states which are homologous to states in ^{87}Y with the addition of the $(d_{5/2})$ neutron particle, namely the multiplet 2^--3^- (corresponding to the pure configuration $\pi(p_{1/2})^{-1}\nu((g_{9/2})^{-2}(d_{5/2}))$, the multiplet 0^--1^--2^--3^--4^--5^- (corresponding to the pure configuration $\pi(f_{5/2})^{-1}\nu((g_{9/2})^{-2}(d_{5/2})))$, and finally the multiplet 1^--2^--3^--4^- (corresponding to the pure configuration $\pi(p_{3/2})^{-1}\nu((g_{9/2})^{-2}(d_{5/2})))$.

Due to the absence of configuration mixing, the ordering of the sequence of levels within each multiplet is just fixed by the two-body matrix elements. A correct ordering and position are predicted for the 4^--5^- and 2^--3^- doublets. For the other multiplets, on the other hand, although the residual interaction leads to a correct amount of total spreading of the multiplets, the centroids are shifted with respect to experiment, and some levels within the multiplets are inverted.

The situation gets modified when we introduce configuration mixing. In this case the model space with particle occupations (in square brackets) used in the calculation are the following: proton: $(f_{5/2})$[5-6], $(p_{3/2})$[3-4] and $(p_{1/2})$[1-2]; neutron: $(g_{9/2})$[8-9], $(d_{5/2})$[0-1], $(s_{1/2})$[0-1], $(d_{3/2})$[0-1] and $(g_{7/2})$[0-1]. In terms of particle-hole description, we have the mixing of both $\pi(1h)\nu(1h)$ and $\pi(1h)\nu(2h-1p)$ configurations, with the proton hole in one of the orbitals $(f_{5/2})$, $(p_{3/2})$ or $(p_{1/2})$, the neutron hole(s) in the $g_{9/2}$ orbital and the neutron particle in one of the orbitals $(d_{5/2})$, $(s_{1/2})$, $(d_{3/2})$ and $(g_{7/2})$. One can immediately, from the amplitudes of the wave functions, single out the multiplets 4^--5^-, 2^--3^- and 0^--1^--2^--3^--4^--5^-, which display a relatively pure character, with large overlaps with the pure configurations $\pi(p_{1/2})^{-1}\nu(g_{9/2})^{-1}$, $\pi(p_{1/2})^{-1}\nu(g_{9/2})^{-2}(d_{5/2})$ and $\pi(f_{5/2})^{-1}\nu(g_{9/2})^{-2}(d_{5/2})$ respectively. In these cases, although a number of level inversion still occurs within the last multiplets, the centroids of the multiplets are now in good agreement with the experimental findings. At variance with these cases, no clear multiplet corresponding to the configuration $\pi(p_{3/2})^{-1}\nu(g_{9/2})^{-2}(d_{5/2})$ is predicted by the calculation. The configuration appears to be rather fragmented into a number of states. Only the 2^- state at 3.55 MeV and the 4^- state at 3.64 MeV display an appreciable overlap ($\approx$ 50 %) with that configuration. Due to the large energy difference between the $p_{3/2}$ and other two proton hole states $f_{5/2}$ and $p_{1/2}$, large mixings do in fact occour between states with one hole in the $p_{3/2}$ orbitals with those corresponding to the hole in the $f_{5/2}$ or $p_{1/2}$ orbital, but with a recoupling of the two neutron holes in the $g_{9/2}$ orbital to angular momentum different from zero.

The problem of large configuration mixing involving states associated with the proton holes is also reflected in the case of ^{87}Y . In this case the model space has been assumed of the form (in square brackets the allowed particle occupations): proton: $f_{5/2}$ [5-6], $p_{3/2}$ [3-4], $p_{1/2}$ [0-2] and $g_{9/2}$ [0-1]; neutron: $g_{9/2}$ [8]. In terms of particle-hole description, this amounts to include negative-parity $\pi(1h)\nu(1h)$ states of the form $[\pi(j)^{-1}\nu(g_{9/2})^{-2})_{I_\nu}]_I$, where the allowed proton hole states include the $p_{3/2}$, the $f_{5/2}$ and the $p_{1/2}$ orbitals, plus positive-parity $\pi(2h-1p)\nu(2h)$ states of the form $[\pi[(j_1)^{-1}(j_2)^{-1}(g_{9/2})]_{I_\pi}(\nu(g_{9/2})^{-2})_{I_\nu}]_I$, i.e. states corresponding to proton core excitation to the proton $g_{9/2}$ orbital. Only the spins $1/2^-$ and $9/2^+$ of the lowest states can be assigned to dominatly proton single particle configurations $(p_{1/2})^{-1}$ and $(p_{1/2})^{-2}(g_{9/2})$, respectively. In the case of the spins s $3/2^-$ and $5/2^-$, on the converse, the lowest states are still associated, as dominant component, to the proton $(p_{1/2})$ state, with a recoupling of the two $(g_{9/2})$ neutron holes. The states collecting most of the single-hole character are predicted to lie at higher excitation energy, precisely at 1.00 MeV for the $5/2^-$ and 1.46 MeV for the $3/2^-$.

It has in any case to be remarked that independently on the overlapping of the son states with the foreseen configurations, OXBASH calculations clearly indicate common configurations for homologous states.

REFERENCES

1)E.Gadioli, E.Gadioli-Erba, R.Gaggini, P.Guazzoni, P.Michelato, A.Moroni and L.Zetta *Z. Phys.* **A310**, 43 (1983)

2) E.Gadioli, P.Guazzoni, S. Mattioli, L.Zetta, G.Graw, R.Hertenberger, D.Hofer H.Kader, P.Schiemenz, R.Neu, H. Abele, G.Staudt, *Phys. Rev.* **C43**, 2572 (1991)

3) E.Gadioli, P.Guazzoni, M.Jaskola, L.Zetta, G.Colombo, G.Graw, R.Hertenberger, D.Hofer, H.Kader, P.Schiemenz, R.Neu, G.Staudt, *Phys. Rev.* **C47**, 1129 (1993)

4) P.Guazzoni, M.Jaskola, L.Zetta, G.Graw, R.Hertenberger, D.Hofer, P.Schiemenz, U.Atzrott, R.Neu and G.Staudt *Phys. Rev.* **C49**, 2784 (1994)

5) U.Atzrott, G.Cata-Danil, G.Graw, P.Guazzoni, R.Hertenberger, D.Hofer, M.Jaskola, P.Schiemenz, G.Staudt, E.Müller-Zanotti, and L.Zetta *Contributions to* Spin'94 Conference, Bloomington, September 15-22, 1994

6) A.Etchegoyen, W.D.M.Rae, N.S.Godwin, W.A.Richter, C.H.Zimmerman, B.A.Brown, W.E.Ormand, J.S.Winfield and L.Zhao, *MSU-NSCL Report* N°524 (1985)

7) A.Hosaka, K.I.Kubo and H.Toki, *Nucl. Phys.* **A444**, 76 (1985)