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HIGH RESOLUTION (p, d) AND $(\vec{d}, t)$ STUDIES OF ^{196}Au AND A TEST OF THE IBM SUPERSYMMETRY CONCEPT * **

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High resolution spectra of the $^{197}\mathrm{Au}(p, d)^{196}\mathrm{Au}$ reaction revealed more than 15 new levels of ^{196}Au in the energy range between 0 and 1MeV. From polarized $(\vec{d}, t)$ angular distributions of differential cross section and asymmetry and from comparison with Distorted Wave Born Approximation (DWBA) calculations transferred angular momenta l, j and spectroscopic factors S_{lj} of the resolved levels have been determined. This leads to restrictions in the spin assignments of states in the odd odd nucleus ^{196}Au. Comparing with predictions, calculated in the extended supersymmetry version of the Interacting Boson Model (IBM), we observe reproduction of relevant features.

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1. Introduction

The introduction of dynamical symmetries in nuclear physics within the framework of the Interacting Boson Model (IBM) [1] was important to establish a consistent picture of collective excitations in nuclei. With the use of supersymmetric dynamical symmetries a unified description of even-even and odd-A nuclei belonging to a common supermultiplet was obtained [2]. About a decade ago it was proposed that the incorporation of the neutron–proton degree of freedom shall allow for the extension of this concept to quartets of nuclei, comprising one even–even, two odd-A and one odd-odd

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nucleus [3]. In early studies it was claimed, that ^{196}Au is an ideal candidate to predict its level scheme from a simultaneous fit of the three other members of the supermultiplet (^{195}Au,^{194}Pt and ^{195}Pt).

To provide more information about the level scheme of ^{196}Au, a collaboration of the ISKP Bonn, the Universität München and the University of Fribourg is presently studying conversion e^--singles, conversion e^-–γ-coincidence and γ-γ- coincidence measurements, following the $^{196}\mathrm{Pt}(d,2n)$ reaction, in addition to the $^{197}\mathrm{Au}(p,d)^{196}\mathrm{Au}$ and $^{197}\mathrm{Au}(\vec{d},t)^{196}\mathrm{Au}$ transfer experiments discussed here. The common aim of these experiments is to establish a complete level scheme of ^{196}Au in the relevant range.

2. The $^{197}\mathrm{Au}(\vec{d},t)^{196}\mathrm{Au}$ experiment and the DWBA analysis

The $^{197}\mathrm{Au}(\vec{d},t)^{196}\mathrm{Au}$ reaction was studied using a 25 MeV deuteron beam with an intensity of 250 nA on 164 μg Au-target and a polarisation of about 60%. Angular distributions from 8 to 48 degree scattering angle in steps of 3 degree were measured with the Q3D magnetic spectrograph, using an array of single wire proportional detectors with additional cathode readout, followed by a plastic scintillator for particle detection [6]. The FWHM line width in the $(\vec{d},t)$ measurements was 7 keV, therefore the data were analysed using the energy calibration and the detected level scheme from a (p,d) experiment (4 keV FWHM) shown in Fig. 1.

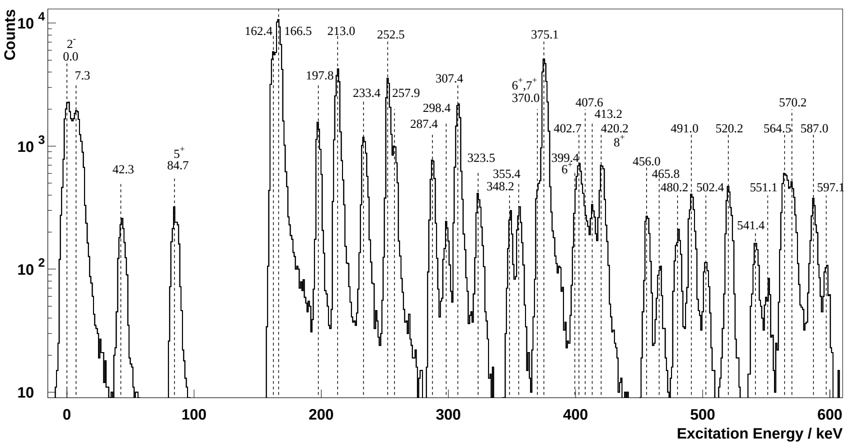

Fig. 1. A $^{197}\mathrm{Au}(p,d)$ transfer spectrum is shown in the energy range between 0 keV to 600 keV. The measurement was performed with an 26 MeV proton beam at an angle of 25° degree in the tandem accelerator laboratory of the University in Garching.

The ground state spin of ^{197}Au is $3/2^{+}$, thus up to four different values of j transfers can contribute to the cross section of an excited state in ^{196}Au. From the shell model there are five orbitals, which may contribute to neutron transfer in this energy range: $3\mathrm{p}_{1/2}$, $3\mathrm{p}_{3/2}$, $2\mathrm{f}_{5/2}$, $2\mathrm{f}_{7/2}$ and $1\mathrm{i}_{13/2}$. Restricting the analysis to these orbits, we expect for negative parity states mixed contributions from $l = 1$ and 3 transfer and for positive parity states pure $j = 13/2$ transfer. The theoretical cross sections and asymmetries are performed with the code CHUCK3. We used a numerical program (MINUIT [7]) to fit the input parameter set of the DWBA calculations.

To evaluate the ^{196}Au transfer data and to determine mixing of the j transfers we also used MINUIT. The extracted spectroscopic factors S_{lj} for lower energies are listed in Table I. The angular distributions of differential cross sections and asymmetries for the ground state doublet, the 84.7 keV and the 233.4 keV level are shown in figure 2. The polarized measurement indicates the presence of different j transfers, it allows for their distinction and the extraction of their respective spectroscopic factors. The angular distributions of all levels are well described by the DWBA analysis.

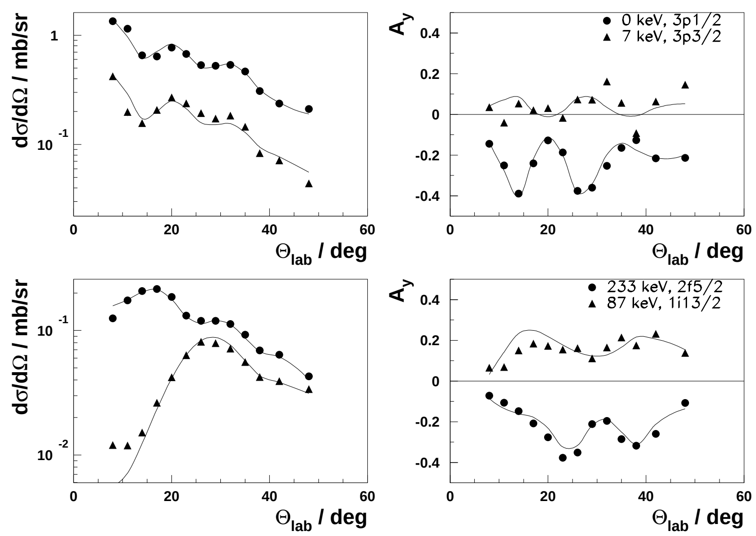

Fig. 2. Angular distributions of differential cross sections and asymmetries of the ground state doublet and of the 84.7 keV and 233.4 keV states.

A restriction of the spin (J_f) of the excited states in ^{196}Au results from the relation between the transferred angular momenta j and initial (J_i) and final spin (J_f) of the nucleus.

$$\mid J_i + J_f \mid \;\leq\; j \;\leq\; \mid J_i - J_f \mid . \tag{1}$$

Thus we get for a pure j transfer and the target spin $3/2^+$ of ^{197}Au up to four values of the final spin state. If however we have detected all four allowed j transfers (as *e.g.* for the 307 keV level), this leads to a definite spin parity 2^- assignment. If a smaller number of transfers are detected, we get a restriction to two, three or four allowed spin states, respectively (compare Table I).

TABLE I

Resolved negative parity states and the extracted spectroscopic factors compared with adopted levels in the energy region between 0 keV and 600 keV.

Energy	$S_{p1/2}$	$S_{p3/2}$	$S_{f5/2}$	$S_{f7/2}$	J^π restr.	adop. lev.
0.0	12.4%		2.3%	0.5%	2^-	0.0
7.4(10)	0.3%	1.7%	0.7%		$1^-, 2^-$	new
42.3(10)		0.5%		0.1%	$0^-, 1^-, 2^-, 3^-$	41.6
162.4(10)	0.2%	1.2%	9.6%	1.9%	$2^-, 3^-$	new
166.5(10)	11.8%	7.4%	2.4%		$1^-, 2^-$	164.8(3)
197.8(10)	1.7%	1.2%	0.6%		$1^-, 2^-$	197.6(3)
213.0(10)			9.3%		$1^-, 2^-, 3^-, 4^-$	211.5(3)
233.4(10)		0.2%	2.6%	0.1%	$1^-, 2^-, 3^-, 4^-$	new
252.5(10)	1.2%	1.2%	4.0%		$1^-, 2^-$	251.0(3)
257.9(10)		0.2%	1.7%		$1^-, 2^-, 3^-, 4^-$	new
287.4(10)		0.5%	0.2%	0.4%	$2^-, 3^-$	286.0(3)
298.4(10)	0.3%	0.2%			$0^-, 1^-, 2^-$	new
307.4(10)	0.6%	1.0%	2.0%	0.7%	2^-	303.5(3)
323.5(10)	0.2%	0.4%	0.2%		$1^-, 2^-$	320.7(3)
355.4(10)	0.1%	0.4%	0.1%		$1^-, 2^-, 3^-$	348.7(3)
375.1(10)		5.3%	2.1%	1.2%	$2^-, 3^-$	370.2(2)
402.7(10)		0.1%	1.0%	0.3%	$2^-, 3^-, 4^-$	400.5(2)
407.6(10)	0.2%	0.2%	0.1%		$1^-, 2^-, 3^-$	new
413.2(10)		0.2%	0.4%		$1^-, 2^-, 3^-, 4^-$	new
456.0(10)	0.2%	0.2%		0.2%	2^-	451.2(2)
465.8(10)	0.1%			0.1%	$2^-, 3^-, 4^-, 5^-$	462.0(3)
480.2(10)	0.2%			0.3%	$2^-, 3^-, 4^-, 5^-$	476.3(3)
491.0(10)	0.3%	0.3%	0.3%		$1^-, 2^-$	487.1(3)
520.2(10)		0.1%	1.0%		$1^-, 2^-, 3^-, 4^-$	516.9(3)
541.4(10)	0.2%	0.2%	0.1%		$1^-, 2^-$	538.1(3)
551.1(10)			0.1%	0.1%	$2^-, 3^-, 4^-$	546.6(4)
564.5(10)	0.9%	0.3%	0.3%	0.3%	2^-	560.6(3)
570.2(10)	0.3%		0.2%	0.4%	$2^-, 3^-, 4^-$	566.5(3)

Compared with the adopted level scheme of ^{196}Au, we get the following new information for negative parity states: The adopted level scheme was from the (d,t) transfer experiment [4], which did not resolve close doublet structures in the spectra, in addition the energy calibration had a systematic shift for energies higher than 300 keV in comparison to our Pt calibration of the ^{196}Pt(p,d) reaction. With a corrected energy calibration the old measurement fits to our data, most peaks are seen in both experiments.

3. Comparison with IBM predictions

The supersymmetry has predictive power for an odd–odd nucleus, when all the parameters can be completely determined by the properties of the even–even and odd-A nuclei. In order to have an analytically solvable supersymmetry, the even-even nucleus and the odd-A nuclei have to fulfill very stringent conditions, which limits the application of these symmetries to a few regions of the chart of nuclei. Here we consider the Pt–Au region, which is appropriate for the $\mathrm{U}_\pi(6/4)\otimes\mathrm{U}_\nu(6/12)$ supersymmetry scheme [3,4]. The states of the odd-odd nucleus is described in terms of the interaction of an O(6) boson core with an odd proton in the $2\mathrm{d}_{3/2}$ orbit and an odd neutron in the $3\mathrm{p}_{1/2}$, $3\mathrm{p}_{3/2}$ and $2\mathrm{f}_{5/2}$ orbits, neglecting the much stronger bound $2\mathrm{f}_{7/2}$ orbital. The best example in the *Au* region should be the quartet ^{194,195}Pt and ^{195,196}Au [3, 4]. The model should be able to describe low lying negative parity states in the odd–odd nucleus ^{196}Au, which provides an interesting test of the predictive power of supersymmetry in nuclear structure. The model is also able to calculate spectroscopic factors of transfer reactions [3, 4, 8]. Since we have not yet full spin assignment of the excited states in ^{196}Au, we compare the IBM predictions with the transferred angular momenta j, which have been determined in our measurement.

In the upper three histograms of figure 3 the experimental values of $\mathrm{S}_{\mathrm{p}1/2}$, $\mathrm{S}_{\mathrm{p}3/2}$ and $\mathrm{S}_{\mathrm{f}5/2}$ are shown and in the lower histograms the respective theoretical ones [4]. First one can see, that the gross structure of the distributions of the spectroscopic factors are reproduced well, especially for $\mathrm{S}_{\mathrm{p}3/2}$ and $\mathrm{S}_{\mathrm{f}5/2}$. In case of the $\mathrm{S}_{\mathrm{p}1/2}$ distributions the strength is mainly concentrated in two transfers as well in theory as in experiment. But the experimental distribution is wider than the theoretic one.

Because of the over all agreement between prediction and experiment, we have assigned some experimental levels. The ground state doublet is assigned as a 2^- and a 1^- state. The ground state was known as a 2^- and for the first excited state only one predicted level with such a low energy is available. Next we have inspected pure transfer cases: For the 42.3 keV state $\mathrm{p}_{3/2}$ transfer and for the 213.0 keV state strong $\mathrm{f}_{5/2}$ only have been observed. If these states have spin 0^- or 4^- respectively, these are the only transitions which are allowed. Since the IBM predicts mixed wavefunctions for the states with the quantum numbers in between we use this for J^π assignment. Further one can try to assign states with characteristic transfer

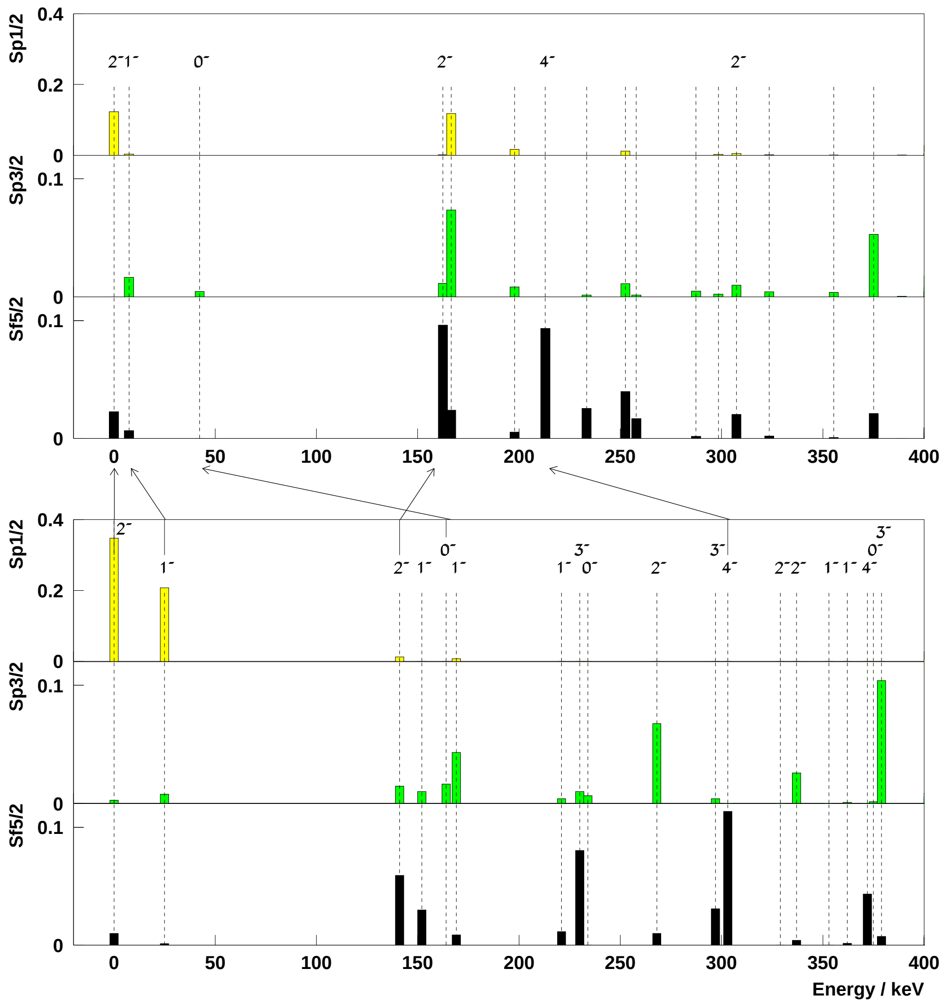

Fig. 3. Experimental (upper histogramms) and theoretical (lower histogramms) spectroscopic factors plotted against the excitation energy. The arrows indicate tentative assignments of levels based on the IBM predictions and the spin restrictions from the DWBA analysis.

mixing, like the 162.4 keV level (compare figure 3). The spin restriction from the experiment can help to classify the levels, too. Further assignments may be tried tentatively, but we better wait for the γ-data announced before.

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