FURTHER EXPERIMENTAL EVIDENCE FOR A DYNAMICAL SUPERSYMMETRY IN ^{196}Pt AND ^{197}Au

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Lifetime measurements in ^{197}Au by the recoil-distance method are used to calculate B(E2) ratios in this nucleus. Together with previous data, these results allow severe tests of the predictions of the dynamical supersymmetry model for E2 transitions in the nuclear supermultiplet ^{196}Pt–^{197}Au.

It has recently been shown [1] that the experimental data on the low-lying levels with positive parity in ^{196}Pt and ^{197}Au suggest the existence of a dynamical supersymmetry (SS) [2] which links together the properties of these 2 nuclei, even–even and odd, in a single theoretical framework. This statement was mainly based on the excitation energies in the 2 nuclei and on the reduced E2 transition probabilities B(E2) between the levels of the $\tau_1 = 3/2$ multiplet [‡1] and the $\tau_1 = 1/2$ ground state of ^{197}Au. Since that paer [1], the SS model has been further elaborated and extended [3]. A distinction is now made between spinor symmetries, described by Lie groups like Spin (6) as in refs. [1,2], and supersymmetries, described by supergroups like U(6/4). The former deal with the properties of one nucleus, ^{197}Au for example, whereas the latter suggests the existence of "supermultiplets" of nuclei, ^{196}Pt and ^{197}Au for example, with the same value of $\aleph = N + M$ (N and M are the numbers of bosons and unpaired fermions, respectively [3]) and with related properties.

The purpose of the present letter is twofold. We first report on a new experimental test of the predictions of the Spin (6) spinor symmetry for the B(E2)'s between the high-spin members of the $\tau_1 = 5/2$ multiplet and the $\tau_1 = 3/2$ levels in ^{197}Au. This is based on lifetime measurements in this nucleus, from which accurate values for the ratios of B(E2)'s between the levels investigated can be deduced. We then compare the experimental B(E2)'s in ^{196}Pt and ^{197}Au with the values calculated using the U(6/4) supersymmetry. We thereby conclude that the predictions of the SS model are accurately verified in this $\aleph = 6$ nuclear supermultiplet, at least for what concerns the reduced E2 transition probabilities.

The lifetimes of levels in ^{197}Au have been measured by the recoil-distance method (RDM) [4]. The states under study have been populated by Coulomb excitation with 171 MeV ^{40}Ar ions, accelerated at the CYCLONE cyclotron of Louvain-la-Neuve and sent on a 1.9 mg/cm^2 target. The decay γ-rays have been detected by a Ge (Li) spectrometer at 0° with respect to the beam direction, in coincidence with backscattered ^{40}Ar ions detected by an annular surface-barrier junction at angles between 145° and 167°. Gamma-ray spectra have been registered for distances between the target and the lead plunger smaller than 50 μm. The experimentally determined recoil velocity was $2.88 \pm 0.06\%$ of c. Further details on the apparatus, on the experimental techniques and on the methods of analysis, in particular on the corrections to the zero-order theory of the RDM, will be given in a later publication.

The levels investigated in the present study are shown in fig. 1. Their energies, spins and parity, and the relative γ-ray branching ratios in their decay are taken from refs. [5,6]. Of particular interest is the position of the $11/2^+$ state at 1231 keV as determined from a recent Coulomb excitation experiment [6]. This is probably

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[‡1] See ref. [2] for a definition of the various quantum numbers used in the present letter.

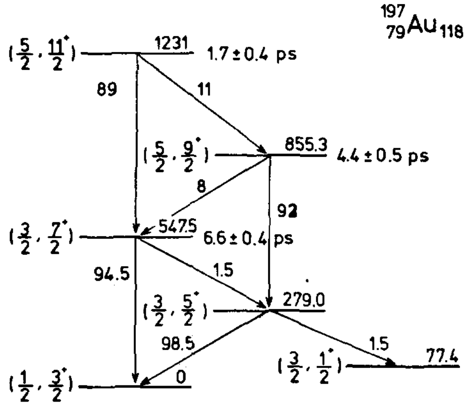

Fig. 1. Partial level scheme of ^{197}Au [6,10]. Only those levels discussed in the present experiment are shown. Excitation energies are in keV. Also indicated are the relative γ branching ratios in percent with estimated experimental uncertainties of ±5%, and the lifetimes we have obtained for the $7/2^+, 9/2^+$ and $11/2^+$ levels in ps. The quantum number τ_1 assigned to the various levels [1,2] is also given.

the missing member of the $\tau_1 = 5/2$ multiplet in the SS model: its calculated energy [1] is indeed 1094 keV. The other members of this multiplet have been discussed in ref. [1]. It should be noticed that, in the present work, the quantum numbers $N = 6, M = 0, \sigma_1 = 6$ and $N = 5$, $M = 1, \sigma_1 = 11/2$ are assigned to those levels of ^{196}Pt and ^{197}Au, respectively, which are considered here. This choice is different from the one of ref. [1] for ^{197}Au wherein $N = 6$ and $\sigma_1 = 13/2$ was adopted; it is suggested by the recently developed U(6/4) supersymmetry [3] for which $\aleph = N + M$ should be conserved. In the latter scheme, the low-lying levels of the nucleus ^{198}Hg, also discussed in ref. [1], have assigned $N = 5, M = 0, \sigma_1 = 5$, and belong to a different nuclear supermultiplet than ^{196}Pt and ^{197}Au. The quantum number τ_1, which is the relevant one for the excitation energies, is however the same in ref. [1] and in the present work.

The values we have obtained for the lifetimes of the $7/2^+, 9/2^+$ and $11/2^+$ levels are also given in fig. 1. As will be apparent later, the relevant quantities for the comparison with nuclear models are the ratios between these lifetimes. They can be determined from our experimental data with higher accuracies than the individual lifetimes since they are almost independent on the uncertainties in the recoil distances and velocity, and weakly affected by the uncertainties in the above-mentioned corrections. Our results for these ratios are: $\tau(9/2^+)/\tau(7/2^+) = 0.656 \pm 0.060$; $\tau(11/2^+)/\tau(7/2^+) = 0.262 \pm 0.029$; $\tau(11/2^+)/\tau(9/2^+) = 0.405 \pm 0.051$. Our value for $\tau(9/2^+)/\tau(7/2^+)$ agrees with the result obtained by Bolotin et al. [7], using the RDM, i.e. 0.75 ± 0.33.

These data allow to calculate the experimental ratios of the B(E2)'s between the $7/2^+$ and $3/2^+, 9/2^+$ and $5/2^+, 11/2^+$ and $7/2^+$ levels given in table 1. Also included in this table are the B(E2) ratios between the

Table 1

Ratios of reduced E2 transition probabilities in ^{197}Au. In the cp model, one assumes that the $3/2^+$ ground state of ^{197}Au arises from the coupling of a 2d3/2 proton to the 0^+ ground state of ^{196}Pt, the first $1/2^+, 5/2^+$ and $7/2^+$, to the first 2^+, the first $9/2^+$ and $11/2^+$, to the first 4^+; the ratio $R(4/2)$ (see text) is taken from a vibrational model description of the core (vibr.) or from the experimental data in ^{196} Pt obtained by Milner et al. [13], Idzko et al. [15] and Bolotin et al. [14]. In the rr model, the $3/2^+, 5/2^+$, $7/2^+, 9/2^+$ and $11/2^+$ levels in ^{197}Au (fig. 1) are considered to be members of a $K = 3/2$ rotational band [6]. In the pr model, the results of Vieu et al. [10] are quoted, the ranges of values given corresponding to different Nilsson orbits included in the calculation; no results are available for the $9/2^+$ and $11/2^+$ levels.

B(E2) ratios	$\frac{1/2-3/2}{7/2-3/2}$	$\frac{5/2-3/2}{7/2-3/2}$	$\frac{9/2-5/2}{7/2-3/2}$	$\frac{11/2-7/2}{7/2-3/2}$
SS model	1	1	0.988	1.257
cp model (vibr.)	1	1	1.571	2
cp model ([13,15])	1	1	0.943 ± 0.079	1.20 ± 0.10
cp model ([14])	1	1	1.218 ± 0.086	1.55 ± 0.11
rr model	–	2.4	1.5	1.782
pr model [10]	0.15–0.75	1.67–2.06	–	–
experiment	0.96 ± 0.12 [a)]	0.94 ± 0.07 [a)]	1.14 ± 0.16 [b)]	1.19 ± 0.26 [b)]

[a)] Ref. [8]. [b)] Present work.

$1/2^+$ and $3/2^+$, $5/2^+$ and $3/2^+$, $7/2^+$ and $3/2^+$ states measured by McGowan et al. [8]; our result for $\tau(7/2^+)$ (fig. 1) agrees with the latter data. Other B(E2)'s are known in ^{197}Au; they are not given in table 1, since their comparison with nuclear models has been discussed previously [1,7–10].

We have calculated the theoretical ratios of B(E2)'s given in table 1 in the framework of three nuclear models. The first, denoted SS, is the dynamical supersymmetry model mentioned at the beginning of this letter. The theoretical expressions given by Iachello [11] have been used, with $N = 5$ and $\sigma_1 = 11/2$ for the levels considered here as suggested in ref. [3], and with the values of τ_1 given in fig. 1 [1,2]. The second model, denoted cp, is the core–particle coupling model, which has often been invoked to describe the energy levels of ^{197}Au [7–9], and wherein an even–even core ^{196}Pt is coupled to a proton in the 2d3/2 orbit. The theoretical expressions given by de-Shalit [12] have been used, with a ratio between the B(E2)'s in the core $R(4/2) \equiv B(\mathrm{E2}, 4^+-2^+)/B(\mathrm{E2}, 2^+-0^+)$ taken from the vibrational model, i.e. $R(4/2) = 2$, or from experimental data in ^{196}Pt [13–15]. The third model is the rotational model, considering, either a symmetric rigid rotor (denoted rr), or the particle–asymmetric rotor description of ^{197}Au proposed by Vieu et al. [10] (denoted pr).

The comparison between the experimental data and the predictions of the three models performed in table 1 clearly shows that the SS model is in very good agreement with experiment while the other models are not, with the possible exception of the cp model with experimental $R(4/2)$. The rotational model in its two versions predicts B(E2) ratios which all disagree with experiment. The SS and cp models generally yield similar predictions, i.e. the equality of the B(E2)'s for the 1/2–3/2, 5/2–3/2 and 7/2–3/2 transitions, and a ratio of 14/11 = 1.273 between the B(E2)'s for the 11/2–7/2 and 9/5–5/2 transitions; they are in good agreement with the experimental data, the latter ratio being 1.04 ± 0.25 from the present work. The two models differ for the B(E2) ratios between the 9/2–5/2 and 7/2–3/2, 11/2–7/2 and 7/2–3/2 transitions, those of the cp model depending on the value of $R(4/2)$ in the core. If the latter is assumed to be vibrational, the predictions of the cp model disagree with experiment. If the experimental $R(4/2)$ in ^{196}Pt is adopted, the degree of agreement depends on the choice between two conflicting sets of data [13–15].

Two remarks should be made on this comparison. First, our determination of the B(E2)'s from the $9/2^+$ and $11/2^+$ levels based on direct lifetime measurements is probably more reliable than those which could be deduced from the yields in multiple Coulomb excitation experiments, since the latter are model dependent. This is less true for the B(E2)'s from the $1/2^+$, $5/2^+$ and $7/2^+$ levels determined by direct Coulomb excitation [8]. Second, more sophisticated versions of the core–particle coupling and rigid-rotor models could be considered, and their predictions could possibly be in better agreement with the experimental data given in table 1. It is, however, interesting to notice that the simplest version of the dynamical supersymmetry model, i.e., the one with just the $j = 3/2$ orbit for the fermion and no mixing between the various levels with the same spin, does better for these data than most other models with the same degree of sophistication.

The agreement with the SS model displayed in table 1 for experimental data in ^{197}Au alone represents a test of the validity of the spinor symmetry described by the Lie group Spin (6) [3]. Similarly, the success of the O(6) limit of the interacting boson model (IBM) [16] in reproducing B(E2) ratios in ^{196}Pt alone [17] is also a test of the same symmetry, whose predictions are the same as those of the IBM [3]. On the other hand, the more general dynamical supersymmetry described by the supergroup U(6/4) [3] links together the B(E2)'s in ^{196}Pt and ^{197}Au: the ratio between the common value of the B(E2)'s for the 1/2–3/2, 5/2–3/2 and 7/2–3/2 transitions in ^{197}Au, and the B(E2) for the 2–0 transition in ^{196}Pt is predicted to be 0.833 with $N = 5$ and $\sigma_1 = 11/2$ in ^{197}Au [3], $N = 6$ and $\sigma_1 = 6$ in ^{196}Pt [16]. The experimental ratio between the average value of the B(E2)'s in ^{197}Au [8] and the one in ^{196}Pt [14, 18,19] is:

$$(0.215 \pm 0.016)\ \mathrm{e^2b^2}/(0.266 \pm 0.002)\ \mathrm{e^2b^2}$$

$$= 0.808 \pm 0.060\ ,$$

in very good agreement with the prediction of the U(6/4) supersymmetry. It should be noticed that the core–particle coupling model where ^{196}Pt is considered as the core of ^{197}Au would yield a value of 1 for this ratio, i.e. 3.2 standard deviations from the experimental result.

It has already been noticed [3] that the parameters used to describe the properties of the members of nuclear supermultiplets corresponding to one value of $\aleph$ in the U(6/4) supersymmetry do not change appreciably when going from one supermultiplet to another. The results of the present paper for the B(E2)'s in ^{196}Pt and ^{197}Au, which belong to a $\aleph = 6$ supermultiplet ($N = 6$ and $M = 0$ for ^{196}Pt, $N = 5$ and $M = 1$ for ^{197}Au), support this remark. The value of α_2, which represents the ratio between the electric quadrupole transition operator and the quadratic generator of Spin (6) [3], is 0.149 eb for ^{196}Pt–^{197}Au ($\aleph = 6$), to be compared with 0.140 eb for ^{190}Os–^{191}Ir ($\aleph = 9$) and 0.146 eb for ^{192}Os–^{193}Ir ($\aleph = 8$) [3]. This is a further hint that an even more general symmetry than the one of U(6/4) should describe the entire region of nuclei with the Os, Ir, Pt and Au isotopes.

In conclusion, the results of the present paper include rather severe tests of the predictions of the dynamical supersymmetry model for reduced E2 transition probabilities in the nuclei ^{196}Pt and ^{197}Au. The agreement is better than for other nuclear supermultiplets to which the same scheme has been applied, i.e. ^{190}Os–^{191}Ir and ^{192}Os–^{193}Ir [3], at least for the observables considered here, so that the supermultiplet ^{196}Pt–^{197}Au would appear to be a better case for the existence of a dynamical supersymmetry in nuclear physics.

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