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## Transition probability studies in $^{175}\text{Au}$

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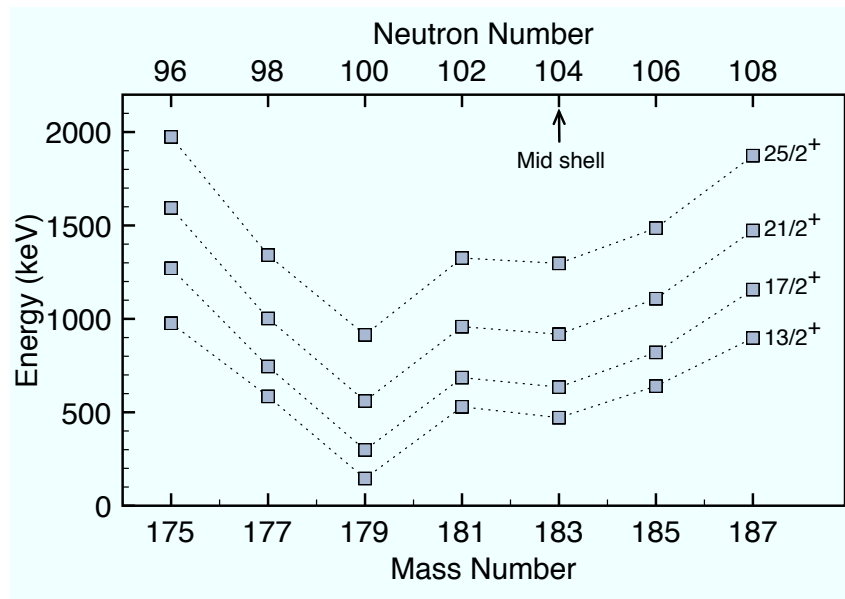
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**Abstract.** Transition probabilities have been measured between the low-lying yrast states in  $^{175}\text{Au}$  by employing the recoil distance Doppler-shift method combined with the selective recoil-decay tagging technique. Reduced transition probabilities and magnitudes of transition quadrupole moments have been extracted from measured lifetimes allowing dramatic changes in nuclear structure within a low excitation-energy range to be probed. The transition quadrupole moment data are discussed in terms of available systematics as a function of atomic number and aligned angular momentum.

### 1. Introduction

Understanding the microscopic structure and dynamics of mesoscopic systems remains a key challenge in contemporary physics. The atomic nucleus has proved to be a unique laboratory for studies of the interplay of fundamental forces of nature. For instance in the neutron-deficient  $Z = 82$  region coexistence of many collective structures has been observed. Neutron-deficient isotopes at and near  $Z = 82$  present us with the most extensive manifestation of the shape coexistence. In the even-mass isotopes this phenomenon has been well established with more detailed nuclear structure data emerging. However, in the odd- $Z$  nuclei spectroscopic fingerprints have been scarce. Only recently due to the development of sophisticated techniques have the spectroscopic studies been extended to odd-mass nuclei at and beyond the neutron mid shell at  $N = 104$  (see Ref. [1] for a review).



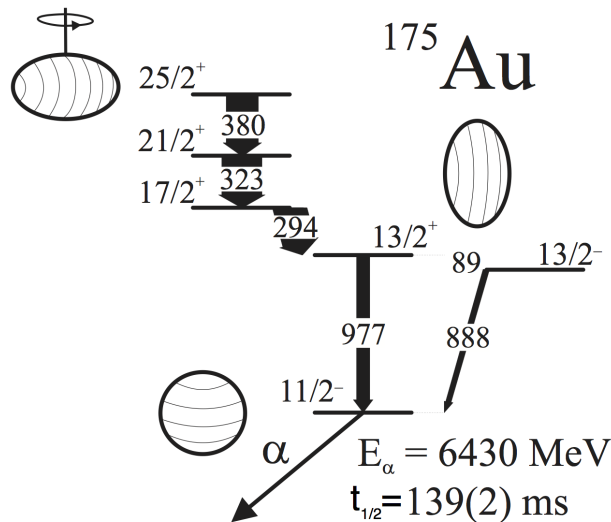
**Figure 1.** Partial energy-level systematics of the proton-particle  $i_{13/2}$  bands in the odd-mass Au nuclei near the neutron mid shell. The energies are relative to that of the  $11/2^-$  state arising from the proton-hole structure. In cases where the  $11/2^-$  proton-hole structure is not firmly established, an estimate has been made. The data are taken from Ref. [6].

A striking example of the shape coexistence can be found in Pb nuclei residing near the neutron mid shell at  $N = 104$ , where three shapes (spherical, oblate and prolate deformed) have been identified to form the three lowest-lying states [2]. In the shell-model picture the deformed configurations appearing as local minima in potential energy surfaces of the mean field are associated with multiparticle-multi-hole excitations across the  $Z = 82$  shell gap [3]. Similarly to the neutron-deficient Pb nuclei, where a beautiful minimum of intruder states is observed at the neutron mid shell, the shape coexistence has been observed in the odd- $Z$  Au nuclei in the vicinity of this region. The present article discusses the triple shape coexistence in terms of the findings of the transition probability measurements in  $^{175}\text{Au}$  [4].

Figure 1 shows the energy-level systematics of the odd-mass Au isotopes near  $N = 104$ . In  $^{175}\text{Au}$ , the positive parity yrast bands observed in the neutron-deficient odd-mass Au isotopes have been associated with a prolate shape and assigned to emerge from  $\pi(i_{13/2})$  intruder excitations [5]. Furthermore, the lowest  $13/2^+$  state has been associated with the oblate configuration. Together with the spherical  $I^\pi = 11/2^-$   $\alpha$ -decaying state deduced from  $\alpha$ -decay characteristics they form an energetically close-lying shape triplet. The partial level scheme relevant for this study is shown in Fig 2.

## 2. Experimental considerations and results

The recoil distance Doppler-shift (RDDS) lifetime measurements in  $^{175}\text{Au}$  were carried out at the Accelerator Laboratory of the University of Jyväskylä, where the  $^{92}\text{Mo}(^{86}\text{Sr}, p2n)^{175}\text{Au}$  fusion-evaporation reaction was used in order to populate the excited states in  $^{175}\text{Au}$ . The  $^{86}\text{Sr}$  beam at an energy of 401 MeV was delivered by the K130 cyclotron with an average intensity of 2 pnA. The 1 mg/cm<sup>2</sup> thick isotopically enriched  $^{92}\text{Mo}$  target and the 1 mg/cm<sup>2</sup> thick Mg degrader foil were housed in the Köln plunger device. The recoiling evaporation residues entered RITU gas-filled recoil separator [7] and subsequently were separated from the background mainly



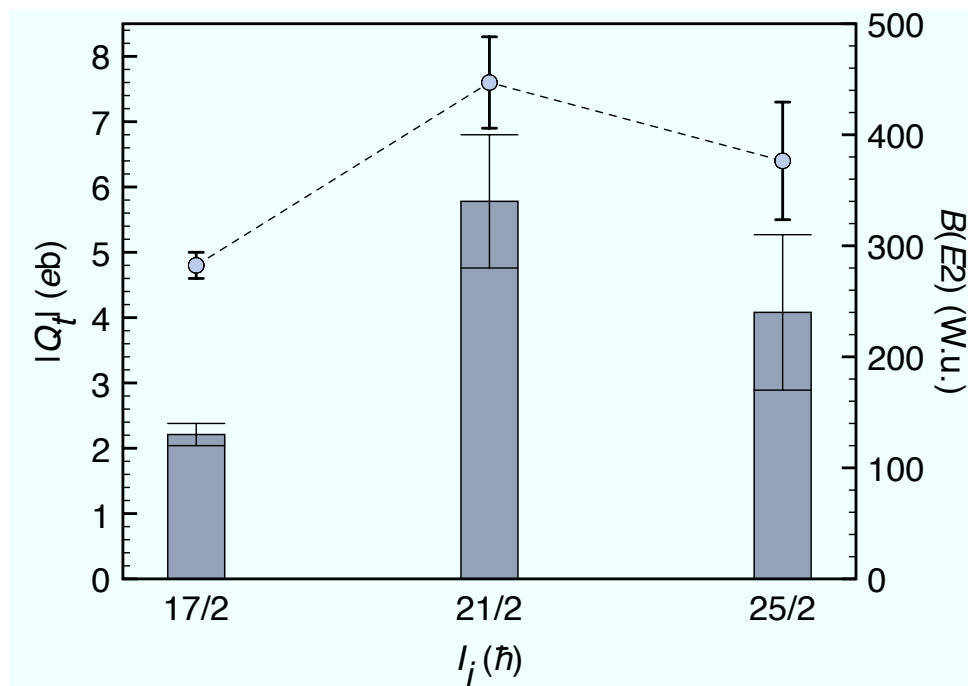
**Figure 2.** Partial level scheme of  $^{175}\text{Au}$ . The data are adapted from Refs. [4, 5].

**Table 1.** Electromagnetic properties of the low-lying yrast transition in  $^{175}\text{Au}$ . The values are taken from Ref. [4].

$E_\gamma$ (keV)	$I_i$ ( $\hbar$ )	$\tau$ (ps)	$B(E2)$ (W.u.)	$ Q_t $ (eb)
997	13/2	300-11000		
294	17/2	44(4)	130(10)	4.8(2)
323	21/2	11(2)	340(60)	7.6(7)
380	25/2	7(2)	240(70)	6.4(9)

arising from fission products and scattered beam. The  $^{175}\text{Au}$  recoils were identified through their characteristic  $\alpha$  decays in the GREAT focal plane spectrometer [8] and subsequently correlated with prompt  $\gamma$  rays recorded with JUROGAM II  $\gamma$ -ray spectrometer surrounding the target position.

Gamma-ray singles spectra tagged with the  $^{175}\text{Au}$   $\alpha$  decays were collected at ten target-to-degrader distances with the JUROGAM II Ge detectors located either at  $158^\circ$  (five detectors) or  $134^\circ$  (ten detectors) with respect to the beam direction. Mean lifetimes  $\tau$  were extracted for the stretched  $E2$  transitions originating from the  $17/2^+$ ,  $21/2^+$  and  $25/2^+$  states according to the principles of the differential decay-curve method [9]. In addition, it was possible to estimate the limits for the lifetime of the  $13/2^+ \rightarrow 11/2^-$   $E1$  transition from the observed Doppler-shifted component and the absence of the degraded component of the de-exciting  $\gamma$  ray. A detailed description of the experimental methods is given in Ref. [4]. The resulting mean lifetimes  $\tau$ , reduced transition probabilities  $B(E2)$  and absolute values of transition quadrupole moments  $Q_t$  are given in Table 1.



**Figure 3.** Transition quadrupole moments  $|Q_t|$  (filled circles) and reduced transition probabilities  $B(E2)$  (filled bars) as a function of the initial spin in  $^{175}\text{Au}$  extracted from the lifetimes measured in Ref. [4].

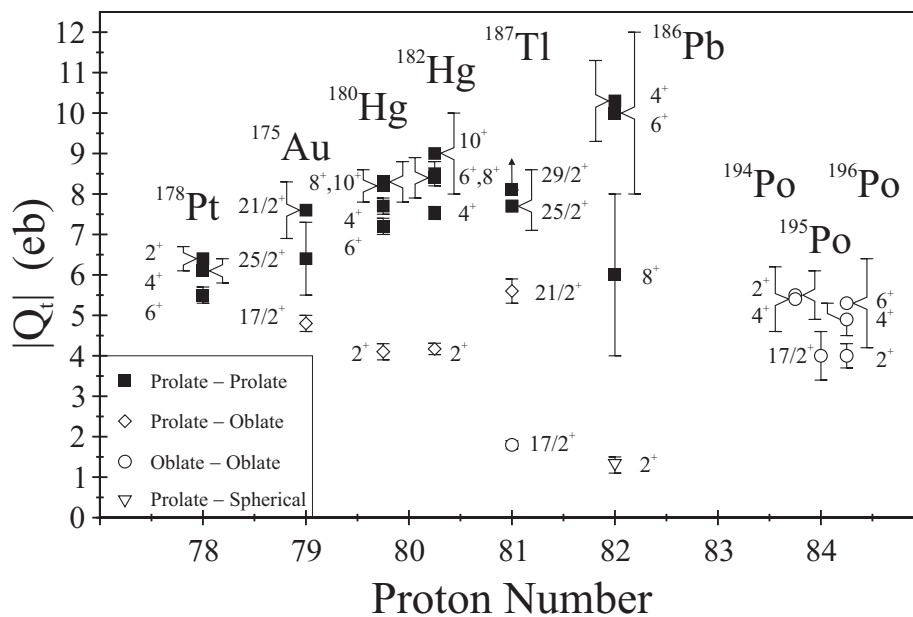
### 3. Discussion

For a rigid rotor nucleus the values of the transition quadrupole moment  $|Q_t|$  can be extracted from the measured  $B(E2)$  values using the rotational model (see, for instance, Ref. [10] for definition). In Fig. 3 the  $|Q_t|$  and  $B(E2)$  values are plotted as a function of the initial spin of the transitions. While the  $|Q_t|$  values for the  $I_i = 21/2$  and  $25/2 \hbar$  are constant within the error bars, the value for the  $I_i = 17/2 \hbar$  transition is considerably lower. This is also reflected by the  $B(E2)$  values and represents typical values for collective rotational bands in the vicinity of  $Z = 82$  [11].

The reduction of collectivity for the  $17/2^+ \rightarrow 13/2^+$  transition can be understood with the change in intrinsic structure of these states. A similar drop in collectivity between low-spin yrast states has been observed in  $^{188}\text{Pb}$  [11] and in  $^{180,182}\text{Hg}$  nuclei, in which the transition connects the two states with different structures [12]. In Ref. [5] the oblate configuration has been proposed for the  $13/2^+$  state, which is in agreement with the present observation. The change in the intrinsic structure from the prolate yrast band at higher spin to the oblate structure of the  $13/2^+$  state hinders the transition rate and therefore results in reduced collectivity.

A qualitative estimate for the mixing amplitude of the oblate component of the wave function of the  $13/2^+$  state can be deduced from the extracted quadrupole moments. Assuming the  $21/2^+$  and  $25/2^+$  states to be pure rotating prolate deformed states as suggested earlier [5], the quadrupole moment for the prolate structure can be extracted as an average of the  $|Q_t|$  values from these states. Furthermore, as the  $|Q_t|$  value for the  $17/2^+ \rightarrow 13/2^+$  transition is hindered by the change in the intrinsic structure between these states, the oblate amplitude can be derived similarly as in Refs. [11, 12] and is on the order of 50%.

The obtained range for the lifetime of the transition from the  $13/2^+$  state to the  $\alpha$ -decaying  $11/2^-$  state yields to an upper limit for the  $B(E1)$  value at the  $10^{-5}$  W.u. level. This is



**Figure 4.** Experimental  $Q_t$  values as a function of  $Z$  for the excited states near  $N = 104$ . The transitions are labelled with the initial spin  $I^\pi$ . The data are taken from Refs. [11, 12, 13, 14, 15, 16].

consistent with the single-proton transition from the mixed oblate-prolate collective state to the  $11/2^-$  near spherical state, in agreement with the suggestion in Ref. [5]. Therefore, these results indicate the existence of three markedly different structures and evolution of nuclear structure from non-collective single-particle structure through the deformed oblate and finally to the deformed prolate structures within less than 2 MeV of excitation energy.

The evolution of collectivity can also be considered as a function of  $Z$  in the region near  $N = 104$  and at or near the  $Z = 82$  shell closure. Figure 4 compares the  $|Q_t|$  values extracted from lifetime measurements as a function of  $Z$  for excited states in this region. The  $|Q_t|$  values indicate that the high-spin states in  $^{175}\text{Au}$  are similar to prolate states in this region. However, the transition originating from the  $17/2^+$  state in  $^{175}\text{Au}$  has a lower  $|Q_t|$  value as discussed above, and is very similar to oblate states in this region. In particular, the yrast bands in  $^{194-196}\text{Po}$  have been discussed as representing rather pure oblate bands [11, 13, 14] and the  $|Q_t|$  values for those bear close resemblance to that from the  $17/2^+$  state in  $^{175}\text{Au}$ .

It is interesting to note that the  $|Q_t|$  values for the prolate structures tend to increase slightly with the increasing  $Z$ , while the corresponding values for the oblate structures remain rather constant. On the other hand, this seems reasonable as the minimum of the intruder configurations have been observed to move away from the neutron mid shell for lighter isotopes. This can be seen in the Au case from Fig. 1.

To conclude, the lifetimes of the low-lying yrast states in  $^{175}\text{Au}$  have been measured using the RDDS method aided by highly selective radioactive tagging technique. The extracted  $B(E2)$  and  $|Q_t|$  values provide evidence for a triad of coexisting shapes at low spin. The measurements indicate that a collective prolate yrast band at higher spin coexists with the oblate structure, which is mixed with the prolate configuration to form the  $13/2^+$  state. Furthermore, the evidence for non-collective  $E1$   $13/2^+ \rightarrow 11/2^-$  transition reflects the single-particle near spherical structure of the  $\alpha$ -decaying  $11/2^-$  state.

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