Lifetime Measurement of the Low Lying Yrast States in $^{189}$Pt

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High-spin states in $^{189}$Pt are populated through the heavy-ion fusion-evaporation reaction $^{176}$Yb ($^{18}$O,5n)$^{189}$Pt at 87 MeV beam energy. An array consisting of 13 HPGe detectors is used in conjunction with the plunger device in CIAE. The lifetimes of two levels in the yrast band are determined by using the recoil distance Doppler shift method. The transition quadrupole moments $Q_{\gamma}$ are extracted. The results show that the $\frac{12}{2}^+$ state has a much larger $Q_{\gamma}$ value than that of the ground state, whereas the value decreases quickly with spin increasing. This may contribute to the shape driving effect of the quasi-neutron from the $i_{13/2}$ orbital.

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Nuclear shapes of the Pt-Au-Hg transitional region are very unstable with respect to $\gamma$-deformation. This region is known to exhibit triaxiality[1] and shape coexistence.[2-8] The occupation of different subshells of specific high-$j$ orbitals near the Fermi surface can induce shape changes for such "$\gamma$-soft" nuclei. For the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of Pt isotopes, there exists a shape transition from prolate to oblate around the chain of $^{189}$Pt.

In this experiment, an array consisting of 11 Compton suppressed HPGe detectors and two planer-type HPGe detectors was used. Four of these detectors were placed at 90°, two at 140° and 150°, and the others at 42°, 45°, 50°, 122°, and 145°, in respect to the beam direction. However, the detectors placed around 90° could not be used to measure lifetimes since the Doppler shift of a $\gamma$ ray emitted in flight is close to zero for these detectors. Details of the plunger setup and the RDDS method will be reported in Ref.[10].

A partial level scheme of $^{189}$Pt deduced from the present experiment is shown in Fig. 1. Lifetime measurements have been made for the two lower-spin states in the yrast band of $^{189}$Pt. Lifetimes were determined from observing the ratio of the fully Doppler-shifted and stopped peaks from data collected by the detectors at a backward angle of 150°. Figure 2 shows that, for different target-stopper distances, Doppler-shifted $\gamma$-ray spectra associated with $^{189}$Pt for selected energy regions include their respective 17/2$^+_1$→13/2$^+_1$ 308-keV and 21/2$^+_1$→17/2$^+_1$ 456-keV transitions. One can clearly see the shifted and unshifted components of the 308 and 456 keV transitions. The relative increase in the intensities of the "shifted" peaks with increasing distance is distinct. The relative intensity
of the observed “shifted” peak with respect to the “stopped” peak depends on the target-stopper distance and it can be easily shown that the lifetime can be obtained from the relation

$$R = \frac{I_{sotp}}{I_{sotp} + I_{shift}} = e^{-D/v\tau},$$

(1)

where $D$ is the target-stopper distance and $\tau$ the level lifetime. The mean lifetime $\tau$ can be extracted from measurements of $R$ at various distance $D$. The data analysis method has been described in detail in Ref.[11]. The lifetimes of $17/2^+$ and $21/2^+$ states are finally obtained, as listed in Table 1.

![Partial level scheme of $^{189}$Pt](image)

**Fig. 1.** Partial level scheme of $^{189}$Pt established in the present work. It is built on the $13/2^+$ isomer at 191.2 keV. The widths of the arrows indicate the relative transition intensities.

The transition quadrupole moment $Q_t$ (in eb) is related with the level lifetimes $\tau$ (in ps) through the expression

$$\tau = \frac{16\pi}{12.24 \times 5\langle I_{K20}|I - 2K|^2 \rangle^2 E_\gamma^2 (I - 2)Q_t^2},$$

(2)

where the $\gamma$-ray energy $E_\gamma$ is in MeV. The Clebsch–Gordan coefficient can be written as

$$\langle I_{K20}|I - 2K|^2 \rangle = \frac{3}{8} I(I - 1) P^2 - K^2 (I(I - 1)^2 - K^2),$$

(3)

where $f_\gamma(I_{K2}, I \rightarrow I - 2)$ is the branching ratio of the $E2$ transition to all $\gamma$ transitions depopulating the level. The values of the branching ratios for the $17/2^+$, $21/2^+$ states at energies of 308, 456 keV in $^{189}$Pt are taken to be 1, which are determined from the previous experiment.[9] According to the relationship between the quadrupole deformation parameter $\beta_2$ and the transition quadrupole moment $Q_t$, $Q_t$ can be expressed as

$$Q_t = \frac{3}{\sqrt{57}} Z r_0^2 A^{2/3} \left( \beta_2 + \sqrt{\frac{5}{64\pi}} \beta_2^2 \right).$$

(4)

**Table 1.** Measured lifetimes and the corresponding $Q_t$ values for the yrast band in the $^{189}$Pt.

| $I^+$   | $E_\gamma$ (MeV) | $\tau$ (ps) | $Q_t$ (eb) |
|--------|-----------------|-------------|------------|
| $17/2^+$ | 308             | 305(8)      | 11.05(29)  |
| $21/2^+$ | 456             | 253(7)      | 2.49(7)    |

In the odd-$A$ neutron-deficient Pt isotopes, a yrast band built on the $i_{33/2}$ configuration has been widely observed. The previous results show that they generally have an isomer at the band-head position. With the neutron number increasing, the isomers were confirmed in the experiment for the isotopes with neutron number larger than 109.[12-19] The nature of these bands is of particular interest. The yrast band for $^{189}$Pt shown in Fig. 1 has been studied in the present experiment. The results show that the $17/2^+$ state has a large $Q_t$ value. With the neutron number 111, the neutron Fermi level is considered to lie at the high $\Omega$ subshell of the $i_{33/2}$ orbital. In Ref.[9], the $13/2^+$ band-head is explained by the occupation of the $i_{33/2}$ 11/2[615] orbital. Valence particles from this orbital have a large oblate shape driving effect. On the other hand, the yrast band in $^{189}$Pt could be described as an $i_{33/2}$ neutron-hole weakly coupled to the oblate deformed nucleus $^{190}$Pt core resulting in similar level spacings with the ground band in $^{190}$Pt. This means that the deformation of the $17/2^+$ state of $^{189}$Pt is larger than the deformation of the ground state of $^{190}$Pt since it is associated with the $i_{33/2}$ structure which drives the nucleus into a more oblate deformed shape. From Eq. (4), one can obtain that the $\beta$ deformation value for the $17/2^+$ state is 0.28. Since the yrast band in $^{189}$Pt has been considered to have an
oblate deformation,[9] the β deformation for the 17/2+ state is suggested as −0.28. It is much larger than the β deformation for the ground state of 190Pt.[15] It is also larger than the deformation[19] for the ground state of 189Pt. This may be one of the reasons why the isomer comes into being at the 13/2+ state.

The derivative can be estimated by the ratio of finite differences of energies and spins between two adjacent states. It is related to this derivative:

\[ \omega = \frac{dE}{dI} \]

As referred to before, the yrast band in 189Pt is suggested as an oblate band with a considerable β deformation near the band head position. However, the β deformation decreases quickly with spin increasing. The rotational hypothesis can be tested by the kinematic moments of inertia \( J^{(1)} \).[20,21] These quantities, deduced from experimental energies and spins, are often used as a measure of the change of collectivity between nuclear rotational bands. Classically, in terms of the spin \( I \) and rotational frequency, \( J^{(1)} \) can be given by \( J^{(1)} = I/\omega \). The rotational frequency \( \omega \) is related to this derivative: \( \omega = dE/dI \), where \( E \) is the excitation energy corresponding to each state. The derivative can be estimated by the ratio of finite differences of energies and spins between two adjacent levels:

\[ \frac{dE}{dI} = \frac{E(I) - E(I - 2)}{\sqrt{I(I + 1)} - \sqrt{(I - 1)(I - 2)}}. \]

Figure 3 shows that the \( J^{(1)} \) values decrease considerably with angular momentum increasing, and the extent of decreasing diminishes at higher spin states. This behavior is generally consistent with the results from lifetime measurements. It is not surprising that the deformation will decrease with spin. The particle plus rotor model calculations[9] show that the valence neutron occupation will change from the \( i_{13/2} \) 11/2[615] orbital to the \( i_{13/2} \) 15/2[660] orbital at higher spin states. A valence particle from this orbital will have a large prolate shape driving effect. Thus the nucleus tends to be driven into a spherical shape. Then the β deformation decreases after the orbital of the valence particle changes.

In conclusion, the lifetimes of two excited states in 189Pt have been determined by using the RDDS method with the HPGe detector array in CIAE. The results show that the first excited state in the yrast band has a large \( Q_t \) value, whereas it decreases quickly with spin increasing. Compared with the β deformation of the ground state, the 17/2+ state is much more deformed. The behavior of the decreasing \( J^{(1)} \) values generally agrees with the results of lifetime measurement.

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![Fig. 3. Kinematic moments of inertia \( J^{(1)} \) as a function of spin for low spin states of the positive-parity yrast band in 189Pt.](image-url)