Prolate and Oblate Shape Coexistence in ^{188}Pt *

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A standard in-beam γ-spectroscopy experiment for ^{188}Pt is performed via the ^{176}Yb(^{18}O, 6n) reaction at beam energies of 88 and 95 MeV, and the level scheme for ^{188}Pt is established. Prolate and oblate shape coexistence has been demonstrated to occur in ^{188}Pt by applying the projected shell model. The rotation alignment of $i_{13/2}$ neutrons drives the yrast sequence changing suddenly from prolate to oblate shape at angular momentum $10\hbar$, indicating likely a new type of shape phase transition along the yrast line in ^{188}Pt.

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Shape coexistence is a major theme in nuclear structure study. The neutron-deficient Pt–Hg nuclei with neutron number $N \sim 10$ are well known to exhibit interesting shape coexistence phenomena due to competing collectivity of prolate and oblate shapes.[1,2] Different structures associated with prolate, oblate, and triaxial shapes within the same nucleus have been identified experimentally,[1,2] and the ground-state shape transitions for the isotopic chains have been observed.[3−5] In the even-A Pt isotopes from $A = 170$ to $A = 190$,[2−5] nuclear structure studies have presented strong evidence for the shape coexistence at low excitation energy. The isotope shift measurements have shown a sharp change of the nuclear charge radius around ^{188}Pt,[3−5] suggesting an oblate ground-state shape for the Pt nuclei with $A > 188$ and a near prolate shape for $A \leq 188$. Therefore, the spectroscopic information of ^{188}Pt is of particular interest as it would show competing collectivity of prolate and oblate shapes. In this Letter, it is our primary aim to extend the level scheme of ^{188}Pt to high-spin states via heavy-ion induced reaction, and to study the shape coexistence phenomenon. Prior to the present work, the high-spin level scheme of ^{188}Pt was reported in the literature.[6,7]

The excited states in ^{188}Pt were populated via the ^{176}Yb(^{18}O, 6n) reaction. The $^{18}O^{7+}$ beam was provided by the tandem accelerator at the Japan Atomic Energy Agency (JAEA). The target was an isotopically enriched ^{176}Yb metallic foil of 2.0 mg/cm^2 thickness with a 7.0 mg/cm^2 Pb backing. The GEMINI[8] γ-ray detector array was used. At the time of this experiment, the array consists of thirteen HPGe's with BGO anti-Compton (AC) shields; six detectors had an efficiency of 40% each and the others had 70% relative to $3'' \times 3''$ NaI. The detectors were calibrated with ^{60}Co, ^{133}Ba, and ^{152}Eu standard sources; the typical energy resolution was about 2.0–2.4 keV at FWHM for the 1332.5-keV line. Due to the location of the compound nucleus ^{194}Pt in the stability line, neutron evaporation channels were dominant for the present projectile and target combination. X-γ-t and γ-γ-t coincidence measurements were performed at beam energies of 88 and 95 MeV, at which energies of ^{188}Pt were large. Here t refers to the relative time difference between any two coincident γ-rays detected within $\pm$200 ns. A total of 240×10^6 coincidence events were accumulated. After accurate gain matching, these coincidence events were sorted into symmetric and DCO matrices for off-line analysis.

Assignments of the observed newγ-rays to ^{188}Pt were based on the coincidences with the known γ-rays.[6,7] Gated spectrum was produced for each of the γ-rays assigned to ^{188}Pt. Based on the analysis of γ-γ coincidence relationships, a partial level scheme for ^{188}Pt has been proposed and presented in Fig. 1. The ordering of transitions in the level scheme was determined according to the γ-ray relative intensities, γ-γ coincidence relationships, and γ-ray energy sums. The transition character was deduced from the measured DCO results. A gated spectrum is shown in Fig. 2, displaying the data quality obtained in the present work.

Variant kinds of nuclear models have been applied to study nuclear shape coexistence. A shell-model study could provide the microscopic origin of shape coexistence by analysing wave functions. The projected shell model (PSM)[9] is a shell model that uses deformed bases and the projection technique.

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The PSM's two-body residual interactions are of the quadrupole plus pairing type, with the quadrupole-pairing term included.[9] In this model, wave functions are written in terms of angular-momentum-projected multi-quasiparticle (qp) states

$$|\psi_M^I\rangle = \sum_\kappa f_\kappa^I \hat{P}_{MK_\kappa}^I |\phi_\kappa\rangle, \quad (1)$$

where the index κ labels basis states. $\hat{P}_{MK}^I$ is the angular-momentum-projection operator[9] and the coefficients f_κ^I are weights of the basis states. For even-even nuclei, $|\phi_\kappa\rangle$ in Eq. (1) is

$$\{|0\rangle, a_\nu^\dagger a_\nu^\dagger|0\rangle, a_\pi^\dagger a_\pi^\dagger|0\rangle, \cdots\}, \quad (2)$$

where $a_\nu^\dagger$ and $a_\pi^\dagger$ are the creation operator for neutrons and protons, respectively. The qp vacuum is $|0\rangle \equiv |\varepsilon\rangle$ at deformation ε, and axial symmetry is assumed in the basis. The qp states are obtained from a deformed Nilsson calculation (with the Nilsson parameters taken from Ref. [10]) followed by a BCS calculation, in a model space with three major shells for each kind of nucleon (N = 4, 5, 6 for neutrons and N = 3, 4, 5 for protons).

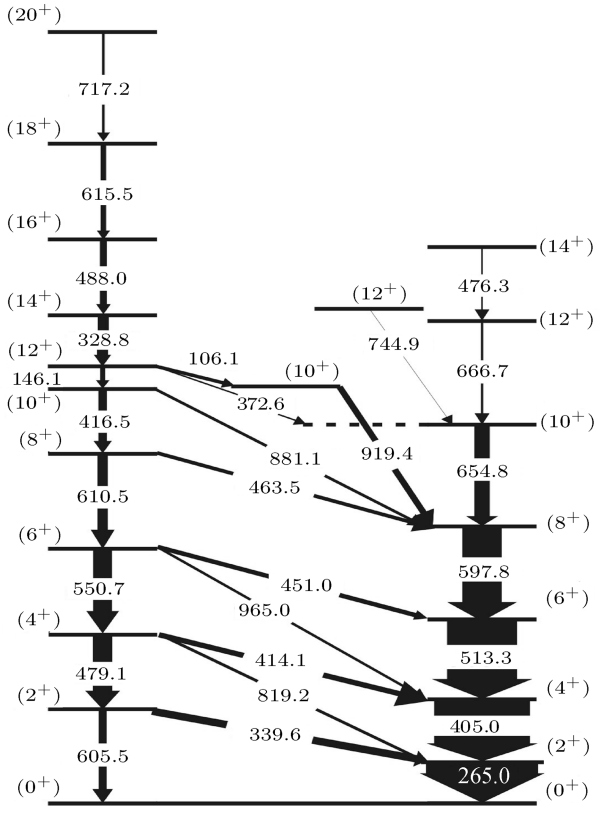


Fig. 1. A partial level scheme of ^{188}Pt.

The calculated energy surface for ^{188}Pt is shown in Fig. 3. These curves show the energies for states with different angular momenta while varying deformation ε from negative values to positive values. There are two pronounced minima, sitting respectively at the prolate and oblate side, with $|\varepsilon| \approx 0.15$. Therefore, the calculation predicts a competing between prolate and oblate shapes with two sets of corresponding collective states. The minimum at $\varepsilon \approx +0.16$, corresponding to a prolate shape, is lower in energy. The calculations suggest that the ground state of ^{188}Pt has a prolate shape, which is consistent with the analysis obtained in Ref. [5]. Compared the calculated results with the experimental observation, we can assign the level sequence, shown on the right hand of Fig. 1, as a prolate band built on the ground state, and the rotational band based on the 605.5-keV state as a oblate band. The calculation indicates that the 605.5-keV state may be a collective state with a oblate shape. Therefore, the transitional nucleus ^{188}Pt presents an excellent example of prolate and oblate shape coexistence.

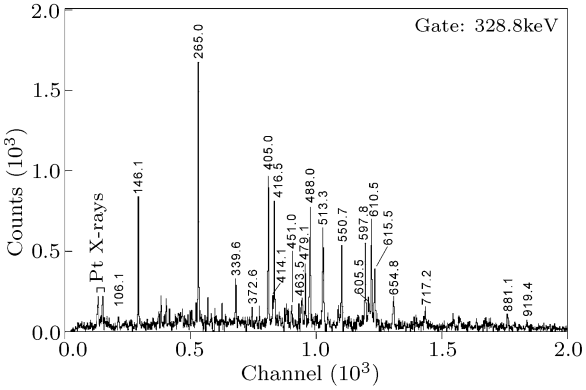


Fig. 2. The γ-ray spectrum gated on the 328.8 keV transition.

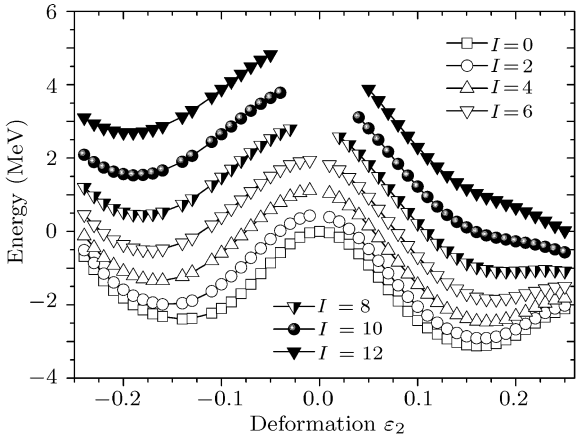


Fig. 3. Energy surface calculation for ^{188}Pt obtained with projection on qp vacuum states only.

Very recently, a new kind of shape phase transition, occurring along an yrast line between states of prolate and oblate shape in an isolated nucleus ^{190}W, has been predicted by Sun *et al.*[11] However, the ex-

perimental data on the excited states of ^{190}W is sparse due to its neutron richness, and the predicted shape phase transition has not yet been proven experimentally. As shown in Fig. 1, the yrast states up to the spin value of $10\hbar$ are the members of the ground state band. However, the yrast states change to the states based on the 12^+ level depopulated by the 328.8-keV transition. If the shape is oblate, occupation of low-K $i_{13/2}$ neutron intruder orbits favours rotation alignment. The $\nu i_{13/2}^2$ configuration was proposed to the 12^+ state. The level scheme of ^{188}Pt clearly shows that the path for the lowest state at each I starts from the prolate ground state, goes up till $I = 10$, and then jumps to the oblate side. The wave functions for the prolate and oblate shapes should be very different, with a very small overlap between them. It is expected that the oblate state at the phase transition point might be a shape isomer. Indeed, the yrast 12^+ state was identified to be an isomer,[7] and the γ-transition between the oblate and prolate states was strongly hindered. Therefore, a prolate to oblate shape phase transition might occur along the yrast line in ^{188}Pt. In the present case, the order parameter is the total spin I.

By using the projected shell model, we have demonstrated the prolate and oblate shape coexistence in ^{188}Pt. Importantly, a new type of shape phase transition might occur along the yrast cascade in ^{188}Pt. The transition is driven by rotation alignment of the $i_{13/2}$ neutrons, which leads to the preferred state suddenly changing shape from prolate to oblate at $I = 10\hbar$. To our knowledge, it is perhaps the first experimental example of a shape phase transition occurring in an isolated nucleus between prolate and oblate shapes.

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