Measurement of the $B(E2; 2_1^+ \rightarrow 0_1^+)$ in neutron-rich ^{182}Hf

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We propose to measure the half-life of the yrast 2^+ state, and thus the $B(E2; 2_1^+ \rightarrow 0_1^+)$, in ^{182}Hf. The ^{180}Hf(^{7}Li, αp)^{182}Hf incomplete-fusion/transfer reaction will be used to populate excited states in ^{182}Hf and γ rays will be detected in the ROSPHERE array of high-purity germanium (HPGe) and lanthanum-bromide ($LaBr_3$:Ce) detectors. The $B(E2; 2_1^+ \rightarrow 0_1^+)$ will give information on the evolution of ground-state collectivity approaching the predicted shape-transition region around $N \approx 116$. It is also expected that additional spectroscopic information on the low-spin states in ^{182}Hf will be obtained in the experiment.

Motivation

Neutron-rich refractory isotopes in the Hf – Pt region are predicted to undergo a phase transition from well-deformed prolate to oblate shapes with a critical neutron number of $N \approx 116$ [1–3]. Figure 1 shows the evolution of the ratio of energies, $E(4^+)/E(2^+)$, and reduced transitions probilities, $B(E2; 2_1^+ \rightarrow 0_1^+)$, for nuclei within this region. The $E(4^+)/E(2^+)$ values suggest a well-deformed rotational behaviour in the known Hf isotopes but the W, Os, and Pt isotopes appear to evolve away from this limit and towards

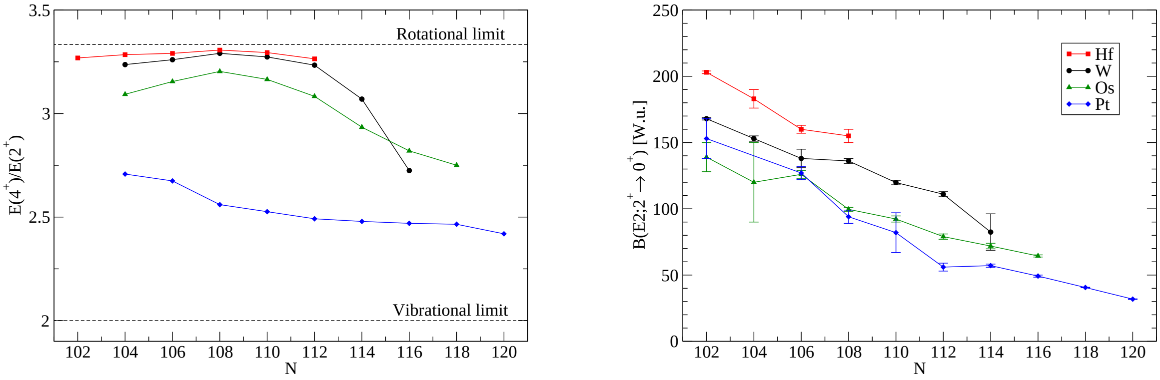

Figure 1: Experimental (left) $E(4^+)/E(2^+)$) and (right) $B(E2; 2_1^+ \to 0_1^+)$ values in even-A Hf, W, Os, and Pt isotopes. Values are taken from the Nuclear Data Sheets except the $B(E2; 2_1^+ \to 0_1^+)$ for ^{174}Hf, ^{176}W [9], ^{178}W [10] and ^{188}W [4].

that of a γ-soft rotor. Conversely, the $B(E2; 2_1^+ \to 0_1^+)$ shows a relatively linear decrease as a function of neutron number for all isotopes as the shell closure at $N = 126$ is approached.

The $B(E2; 2_1^+ \to 0_1^+)$ reduced transition probability is an excellent probe of ground-state collectivity, with higher $B(E2)$ values indicating more collective transitions. At present, the successful measurement of the half-life of the yrast 2^+ state in ^{188}W in Bucharest [4] marks the only $B(E2; 2_1^+ \to 0_1^+)$ measured for nuclei on the neutron-rich side of stability past the proton mid-shell ($66 < Z < 82$). Thus, a precision measurement of the lifetime in ^{182}Hf is desirable to further investigate changes in the collectivity in this transitional region. Based on the systematics of lighter Hf isotopes, a half-life of around 1.5 ns is expected for ^{182}Hf – ideal for fast-timing measurement.

The measurement will also give an estimate of the deformation in this nucleus. The behaviour of ^{182}Hf is expected to be close to the rigid rotor limit and so the simple rotational model of Bohr and Mottelsson [5] can be used to extract an estimate of the quadrupole deformation. This will be compared to existing theoretical predictions for deformation in this region (e.g. [2, 6]) along with new predictions to be performed for this experiment.

As the proposed ^{7}Li-induced reaction gives significant population of low-spin, non-yrast states, it is also noted that the experiment is likely to give additional spectroscopic information on low-spin excited states in this nucleus. The second 2^+ state in ^{182}Hf is only tentatively identified [7, 8] and little of the non-yrast structure has been established. The energy ratio of the yrast and second-excited 2^+ states is an important measurement in quantifying the degree of γ-softness of the nuclear shape.

Experimental Details

We propose to measure the half-life of the yrast 2^+ state in ^{182}Hf using in-beam fast timing with the ROSPHERE array of high-purity germanium (HPGe) and lanthanum-bromide

(LaBr$_3$:Ce) detectors. ^{182}Hf will be populated using the ^{180}Hf(^{7}Li, αp)^{182}Hf incomplete-fusion/transfer reaction, with the ^{7}Li beam provided by the 9 MV Tandem van de Graaff accelerator. The feasibility of this reaction for in-beam fast-timing measurements has previously been demonstrated at Bucharest by the measurement of the yrast 2^+ state half-life in ^{188}W [4]. Figure 2 shows the final time spectrum obtained from this experiment.

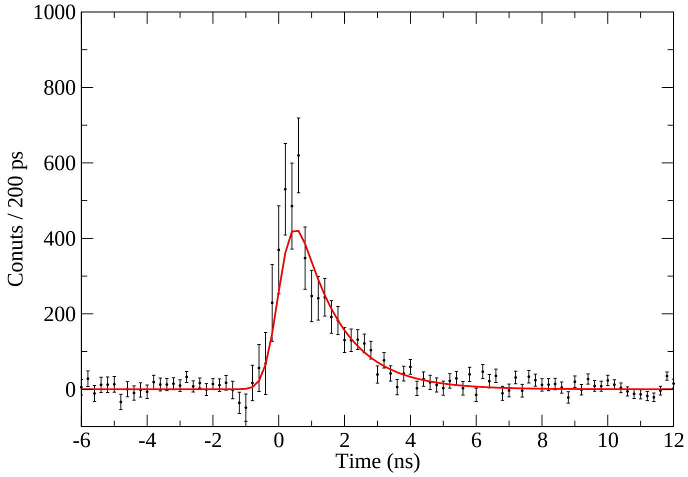

Figure 2: Time spectrum for the decay of the yrast 2^+ state in ^{188}W measured from the time difference between the 143-keV transition and all observed feeding transitions. The solid line represents a Gaussian-exponential convolution fit to the data giving a half-life of $t_{1/2} = 0.89(13)$ ns.

A partial level scheme for ^{182}Hf relevant to this proposal is shown in Fig. 3. Ideally, the half-life of the yrast 2^+ state will be measured from the time difference between the full-energy photopeaks of the $4^+ \rightarrow 2^+$ (224-keV) and $2^+ \rightarrow 0^+$ (98-keV) transitions. A HPGe gate would be placed on the $6^+ \rightarrow 4^+$ (344-keV) transition to create a clean LaBr$_3$:Ce $E_{\gamma 1}$-$E_{\gamma 2}$-ΔT cube. However, due to the low cross-section for ^{188}W with the equivalent reaction, it was necessary to use a sum of HPGe gates on all feeding transitions and take the time difference between the 143-keV photopeak and a region of the LaBr$_3$:Ce spectra from 250- to 750-keV. This continuous region contained the photopeaks and Compton-scattered γ rays of any transition feeding the yrast 2^+ state and higher lying states in ^{188}W. Though it is hoped that with the improved peak-to-total of the ROSPHERE, a time-diffence spectrum using only full-energy photopeak gates can be created, it is likely that a similar procedure using a wide "start" gate will also be needed for ^{182}Hf.

Rate Estimates and Beam-Time Request

In 10 days of beam time with a beam energy of 31 MeV and an average beam intensity of ∼4 particle-nA, a time spectrum (shown in Fig. 2) with ∼2000 counts was obtained for the yrast 2^+ state in ^{188}W. This required the sum of any direct and indirect feeding transitions with wide stop gates that included the Compton continuum of the spectrum. A significant proportion of these statistics were from feeding by non-yrast states in ^{188}W. The amount of non-yrast feeding is expected to be smaller for ^{182}Hf due to the more γ-rigid shape predicted for this nucleus, thus rate estimates for the proposed experiment are based on the yrast feeding only. Using only a single HPGe gate on the $6^+ \rightarrow 4^+$ transition in ^{188}W to generate the time spectrum yielded ∼600 counts (60 counts per day) but the poor peak-to-total ratio made it impossible to accurately determine the half-life from this spectrum.

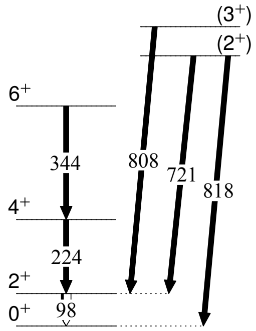

Figure 3: Partial level scheme of ^{182}Hf [7]. The tentative spin and parity assignments are taken from Ref. [8] which suggests that they are the bandhead and first rotational state of the γ band.

The cross-section and spin input for this reaction is assumed to be approximately the same as that for the equivalent ^{7}Li + ^{186}W reaction used to populate ^{188}W. It was seen in the ^{7}Li + ^{186}W reaction that increasing the beam energy from 31-MeV to 33-MeV increased the production cross-section and spin input for ^{188}W. At 33-MeV, the coincidence rate between the $6^+ \rightarrow 4^+$ and $2^+ \rightarrow 0^+$ transitions in ^{188}W was $\sim$75% greater than at 31-MeV. For this reason, a beam energy of 33-MeV is chosen to maximise population of ^{182}Hf. However, the cross-section for the strongest fusion-evaporation channels was also increased by $\sim$70% with the higher beam energy and so the beam energy in the proposed experiment can be adjusted closer to the Coulomb barrier ($\sim$29 MeV) if contamination from fusion-evaporation reaction channels in the online spectra is large. In the previous experiment, ^{188}W represented $\lesssim 0.5\%$ of the total γ-γ statistics obtained.

The new ROSPHERE array will improve the HPGe efficiency of the $6^+ \rightarrow 4^+$ gate from $\sim$1.4% at 552-keV [11] with 8 HPGe detectors for ^{188}W to $\sim$2.1% for the 344-keV transition [12] in ^{182}Hf. The improved peak-to-total ratio due to the Compton-suppression of the ROSPHERE array should ensure that fewer counts are required in the final time spectrum to measure the half-life accurately. It is estimated that $\geq$800 counts will enable us to determine the half-life with better than 15% accuracy.

Assuming similar experimental conditions to the ^{188}W experiment and taking into account the new HPGe efficiency and higher conversion coefficient for the $2^+ \rightarrow 0^+$ ($\alpha = 3.85$ for ^{182}Hf [7], $\alpha = 1.00$ for ^{188}W [13]), we can expect to obtain $\sim$70 counts per day in a time difference spectrum utilising only a single gate on the $6^+ \rightarrow 4^+$ transition in ^{182}Hf. In 12 days of beam time we will obtain a minimum of $\sim$800 counts in the time difference spectrum, enough to measure the half-life of the yrast 2^+ state in ^{182}Hf with a good degree of accuracy. **Thus we request 12 days of beam time**.

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