Lifetime of the isomeric intruder state in ^{105}Ru

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Abstract

We propose to measure half-lives of several excited states in ^{105}Ru by using ^{13}C-induced neutron transfer reaction. In this nucleus, at low excitation energies, single-particle and seniority isomers emerge and compete with collective degrees of freedom. In order to study the interplay between these modes we propose to measure lifetimes of the low-lying excited states by using the hybrid RoSphere. Of particular interest is the lifetime of the intruder state at 209 keV. Preliminary results, had shown that the lifetime of this particular states is by ≈ 10 orders of magnitude shorter than previously expected. The results from the present proposal are thus expected to have an impact on our understanding of the interplay between the single-particle and collective degrees of freedom in this mass region.

1 Motivation

On the Segré chart, ^{105}Ru is located between its heaviest stable isotope ^{104}Ru [1, 2] and the most exotic ^{117,118,119}Ru nuclei, produced in relativistic fission [3, 4, 5]. Being just on the edge of the line of β-stability, only few experimental methods can be used to populate its excited states. So far, the nucleus was studied in the ^{105}Tc β-decay [6], ^{104}Ru(d,p) reaction [8, 7] and n-capture on ^{104}Ru [10, 9]. More recently, ^{105}Ru was studied from $(d, p\gamma)$ at IFIN-HH. It should be noted, however, that these reaction mechanisms are highly selective and populate only low-spin states. In the 1990s the high-resolution high-granularity multidetector γ-ray arrays become available, which have enabled the use of induced fission reactions for γ-ray spectroscopy, providing the opportunity to fill in the gap of transitional nuclei situated between the line of beta stability and the most exotic neutron-rich nuclei produced in fission. This type of reactions also provide the opportunity to obtain some of the higher-spin states in these "transitional" nuclei. Thus, by using induced fission reaction, the intruder negative-parity band in ^{105}Ru was observed for the first time and extended up to $(31/2^-)$ [11]. There, the spin and parity assignment of $J^\pi = 11/2^-$, made to the band head, was based on systematics and theoretical assumptions. This assignment was then extrapolated towards the most exotic neutron-rich ruthenium nuclei. However, recent studies[1] had shown that the spin value of that state is grossly overestimated. If so, the proposed experiment will have a large impact on the spin/parity assignments in the heavier Ru isotopes, and hence on our understanding of the interplay between the single-particle and collective degrees of freedom in this mass region.

[1]Our previous $(d, p\gamma)$ experiment at IFIN-HH

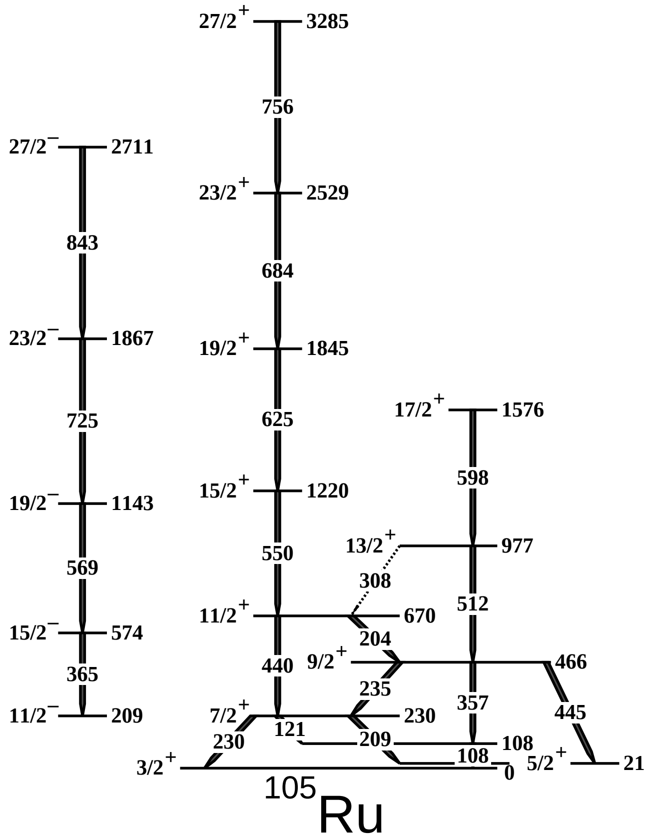

Figure 1: Partial level scheme of ^{105}Ru as observed in refs. [11] and [12].

More recently, the ^{105}Ru was studied from a ^{30}Si+^{168}Er induced fission reaction [12]. The partial level scheme, obtained in this study is shown in Fig. 1.

1.1 Intruder states

As discussed, being the first neutron-rich odd-mass nucleus in the ruthenium isotopic chain, ^{105}Ru is crucial for the understanding of the structure of the more exotic ruthenium nuclei. For example, in ref. [11] the spin/parity assignments of the yrast bands in all odd-mass ruthenium isotopes are based on the systematics. Thus, to test the spin and parity assignment made to the 209-keV isomeric state in ^{105}Ru, we would like to measure its half-life. The half-life of this state is sensitive to is J^{π} value. If it is a $11/2^{-}$ state, as assigned in ref. [1], it would decay via $E3$ transitions to some of the lower-lying $5/2^{+}$ states, leading to the isomer half-life of the order of few seconds. However, the $L = 5$ value from (d, p) reaction suggests that J^{π} could also be $9/2^{-}$ or even less. If this scenario is valid, the state would decay via quadrupole or even dipole transitions to the lower-lying $5/2^{+}$ states, leading to half-life of the order of few nanoseconds.

Indeed, in a recent experiment performed at NIPNE, we have observed a much shorter half-life of the 209-keV isomer then previously expected. In this experiment we have used a chopped proton beam in order to cover the long time range needed to detect $E3$ transitions, expected to de-populate the isomeric state. From this experiment, for the first time, we have observed a coincidence between the 365-keV transition from the intruder band and the 143-keV transition, known to de-excite the 163-keV state (not shown in Fig. 1) to the $5/2^{+}$ isomer at 21 keV. Surprisingly, these coincidences were within the 200 ns time window suggesting that the spin of the isomer is lower than previously expected. Given that this particular experiment was optimized for much longer half-lives, we propose to re-measure the half-life of the isomeric states by using shorter time gate interval in order to collect more statistics and to use $\gamma - \gamma(t)$ coincidences. In our previous experiment we have lost a significant amount of data due to the off-beam type of measurement of $\gamma(t)$ with respect to the beam.

1.2 Single-particle and seniority states

By using prompt spectroscopy and the hybrid RoSphere, we would be able also to measure half-lives of some low-lying positive parity states in ^{105}Ru. Some of these states are characterized by large spectroscopic factors, hinting at their single-particle nature. Others, having small spectroscopic factors, appear to have a more complex nature [12] involving seniority isomerism and triaxial collectivity.

Given that in the j^3 scheme of identical particles placed on the same orbit, the $M1$ transitions between the member of the same multiplet are forbidden [13], measurements of half-lives of low-lying states can hint at the persistence of such configurations away from the doubly magic nuclei. The decays of these states will be governed by the the $E2$ components of the respective transitions and their magnitude can be used to measure to what extent collectivity is present.

This study will be a continuation of the series of measurements we had in the past at IFIN-HH, where lifetimes in $^{99-103}$Ru were measured [14].

1.3 Collectivity

The collective excitations in the Ru nuclei have been extensively examined within different theoretical models. Among the most recent systematical study of the excited states in the odd-mass ruthenium isotopes was performed in ref. [16], which along with previous results from fast-timing measurements in some Cd, Mo and Ru nuclei served for the PhD Thesis of S.Kisyov.

2 Experimental set-up

For the purpose of the present experiment we plan to use the RoSphere array in its hybrid configuration. The yields below are made with a RoSphere efficiency of 2%.

3 Beam-time estimation

With the present document we propose to measure the half-life of the 209-keV isomeric state at RoSPHERE, comprising 11 $LaBr_3$:Ce and 14 HPGE detectors. Based on our previous experience, we propose to perform an induced by ^{13}C neutron transfer reaction on ^{104}Ru target. In the last day of our previous experiment, where mainly d was used, we had switched the beam to ^{13}C and found that the yield is similar to that of the d, p reaction. Therefore, based on that experience, we **request for a 5 days of beam time with ^{13}C** at a **beam energy of 40** MeV. The beam energy is select to be at approximately the Coulomb barrier to suppress the fusion channel. To stop the recoils, we will need the old 50 mg/cm^2-thick target enriched to 98.5% in ^{104}Ru.

4 Summary

We propose to measure the half-life of the 209-keV isomer via $365\gamma - 143\gamma(t)$ coincidences. The nucleus will be populated in ^{104}Ru+^{13}C neutron transfer reaction. Emitted γ-rays will be detected by the RoSphere detector array in its hybrid configuration.

Experimental details:

- **Beam:** ^{13}C at 40 MeV
- **Target:** 50 mg/cm^2 thick, enriched in ^{104}Ru
- **Beam Current:** 2 pnA
- **Detectors:** RoSphere

To perform the suggested measurements, i.e. the half-life of the isomeric state via double coincidences and half-lives of other low-lying positive-parity states via triple coincidences, **5 days of beam-time are requested**.

The new data will be used for the PhD thesis of a student at the Faculty of Physics, University of Sofia, who is expected to start effectively from Jan.2018 .

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