Fast-timing measurements in ^{102,104,106}Pd

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Abstract

We propose to measure the half-lives of the negative-parity excited states in ^{102,104,106}Pd produced in fusion/evaporation reactions. These states are usually interpreted as based on two quasi-particle excitations. The half-life of the excited states are related to the transition strengths and hence to the underlying nuclear structure.

1 Motivation

According to NNDC [1] and Raman's best fit equation [2], the quadrupole deformation parameter β_2 is approximately equal to 0.19 for ^{102,104,106}Pd nuclei. In each of these weakly deformed nuclei the g.s.b. energies slightly increase with the angular momentum (Figure 1). Their $R_{4/2} = E_{4^+}/E_{2^+}$ ratio is approximately equal to 2.4, a value well between the typical values for pure vibrational and rotational collective modes (Figure 2). Therefore, the low-lying states in these nuclei are typically described as collective excitations, most probably involving a large degree of γ-instability. At higher excitation energies back-banding effect occurs in the even-even palladium nuclei. It is observed at rotational frequencies of $\hbar\omega \approx 3.5$ MeV (Figure 3) and is associated with a $h_{11/2}$ neutron pair-braking ([4] and references therein). Also, for energies higher than 2 MeV negative-parity states with $J^\pi \geq 3$ appear. The $J^\pi = 3^- - 8^-$ states have irregular energy spacing, while the states with $J^\pi > 8^-$ are grouped in $\Delta J = 2$ quasi-rotational bands with energy spacing similar to that of the ground state band. These level sequences have been interpreted in the past as collective bands, based on two quasi-particle excitations involving $\nu d_{5/2}$, $\nu g_{7/2}$ and $\nu h_{11/2}$ single-particle orbitals [5]. And while the levels with $J^\pi > 8^-$ can be "easily" understood in the framework of the two quasi-particle + rotor model, the negative parity states with $J < 9$ might have even more complex nature, involving decoupling of the two neutrons from the axis of symmetry and re-orientation with respect to the rotational axis. The nature of the lower-lying negative-parity states in the lighter ^{104,102}Pd$_{58,56}$ nuclei might be even more complicated giving their neutron number is close and equal to 56 - one of the "the octupole-collectivity magic numbers" [6]. In this mass region signatures of octupole collectivity have been observed around ^{96}Zr [8] and ^{98}Mo [9], suggesting that this type of collectivity might be still presented in the palladium isotopes discussed in the present proposal.

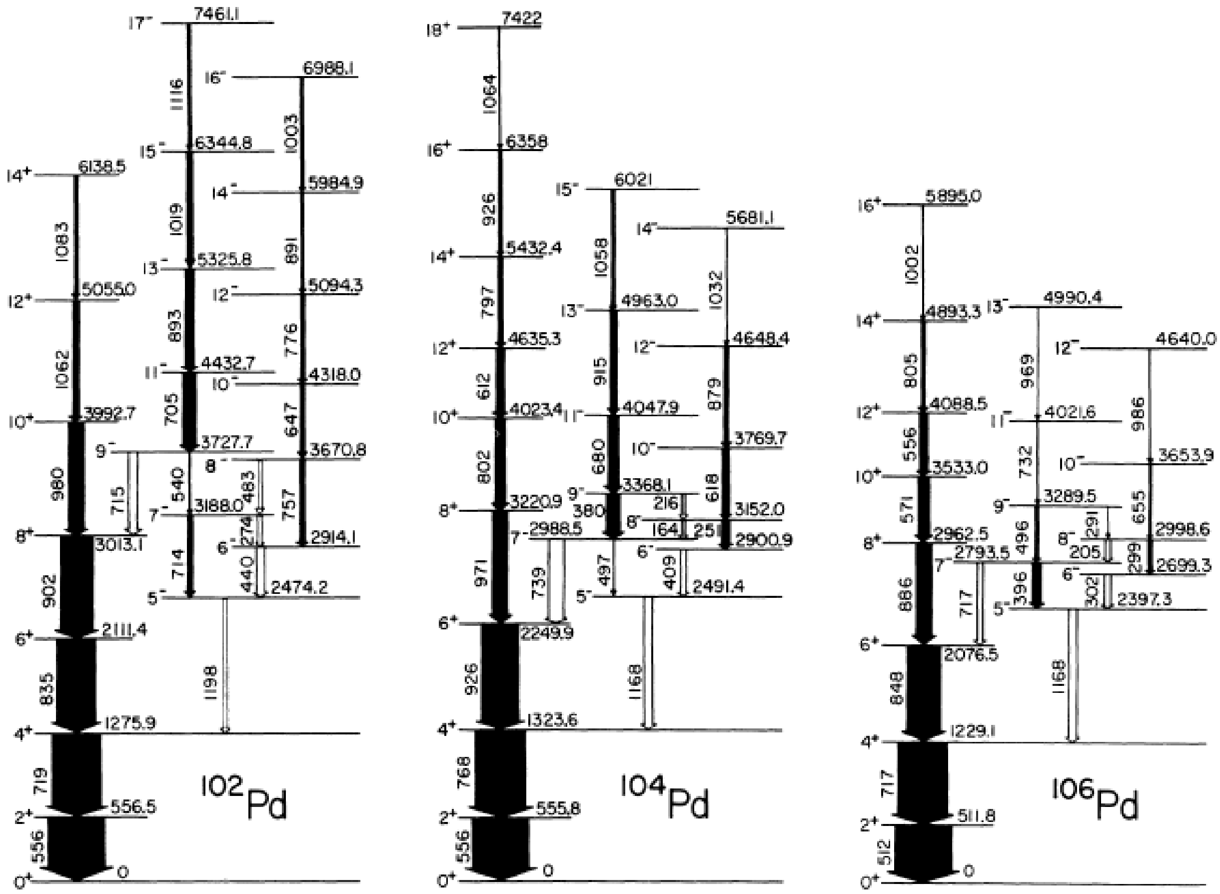


Figure 1: Partial level schemes of ^{102,104,106}Pd from [3]. Additional states, populated in (^{13}C,3nγ) reactions are also given there.

In order to study, the single-particle and collective degrees of freedom and their interplay we propose to measure the half-lives of the states with negative-parity. The half-lives are directly related to the transition strengths and hence to the underlying dynamics.

2 Half-life estimation

In ^{106}Pd, $T_{1/2} = 2.0$ ns of the 4^- state at 2306 keV has been measured by using $\alpha\gamma(t)$ delayed coincidences following $(\alpha, 2n\gamma)$ reaction [1]. Also, the half-lives of $(6)^-$ and (9^-) states placed at 2699 keV and 3290 keV [Figure. 1] were determined in the same study to be $T_{1/2} = 0.5$ ns and 0.2 ns, respectively. $T_{1/2} = 1.1$ ns was obtained for the (4^-) state in ^{102}Pd [1] by using $\alpha\gamma(t)$ delayed coincidences [1] in $(\alpha, 2n\gamma)$ reaction. These half-lives, along with the known γ-ray intensities, multipolarities, mixing ratios and conversion coefficients [1] allow to determine the reduced transitions probabilities for the respective E1, M1, E2 and M2 transitions in ^{106}Pd and ^{102}Pd [Table 1]. In several cases, transitions of the same type have quite different transition strengths allowing to determine the range of the hindrance factors in this mass and spin range. Then, assuming the structure of the nuclei do not change abruptly from ^{102}Pd to ^{106}Pd, the half-lives of the negative-parity states in ^{102}Pd to ^{104}Pd were calculated. Table 1 lists the level energies E_{level} and J^{π} assignments as given in NNDC [1] along with the estimated half-lives

Isotope	E_{level} [keV]	J^{π}	$T_{1/2}$ [ps]
^{102}Pd	2474	5^-	211
	2914	$6-$	110
	3188	7^-	57.9
	3670	8^-	35.4
	3728	9^-	45.3 - 7.7 10^4
^{104}Pd	2491	5^-	1090
	2901	6^-	111
	2989	7^-	32.2 - 105
	3152	8^-	5100
	3368	9^-	1260

Table 1: Excited states and decay properties in ^{102,104}Pd.

$T_{1/2}$ in ^{102,104}Pd. The estimated half-lives, listed in the table, are within the time range of the Magurele Fast-Timing Array

Figure 2: R4/2 ratio for the even-even nuclei in the $40 < Z < 50$ region [7]

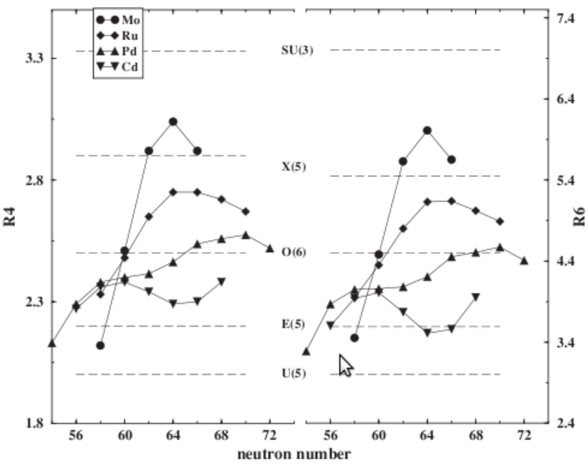
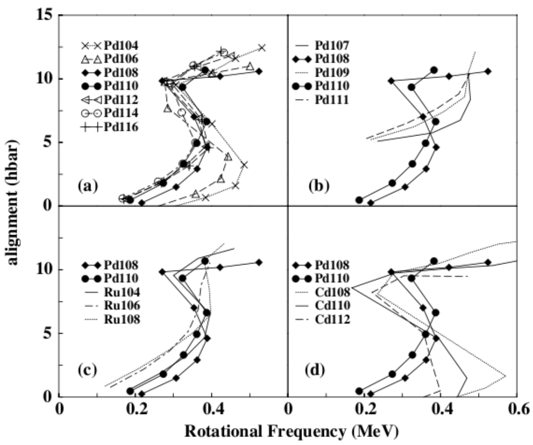


Figure 3: Alignment plots [4]



3 Experimental Set Up

Lifetimes in the sub-nanosecond range will be measured by using the specially designed system for in-beam fast-timing measurements at NIPNE. It comprises eight HPGe detectors working in coincidence with eight $LaBr_3$:Ce detectors [10]. The system is triggered by two $LaBr_3$:Ce fired in coincidence with one HpGe detector. The half-life of the level of interest will be measured by using the time difference between the feeding and de-exciting gamma-rays detected by any two of the five $LaBr_3$:Ce detectors under the condition that the cascade is fed by a prompt γ-ray detected by one of the HpGe detectors.

4 Preceding experience

In the last two years we have performed a number of experiments at Magurele, aiming on sub-nanosecond half-lives. Transitions strengths were studied in ^{103,105,107}Cd, populated in (^{12}C, 3nγ) reactions [11]. In-beam fast-timing experiments aiming on ^{95,96}Mo, following ^{18}O+^{82}Se reaction [12], were also carried out. Excited states in ^{111}Sn were produced via ^{107}Ag+^{7}Li reaction.

5 Beam time estimation

Excited states in ^{102,104,106}Pd will be populated in (^{13}C,3nγ) reactions on ^{92}Zr, ^{94}Zr and ^{96}Zr. These reactions were previously used to populate yrast states up to 18$\hbar$ [3]. The reactions cross-sections are estimated to $\approx$ 100 mb for beam energy of 45 MeV by using CASCADE. The Coulomb barrier for this reaction is 37 MeV. Given that the energy loss of 45-MeV ^{13}C beam in ^{96}Zr target is 1.6 MeV/(mg/cm^2) a target with thickness of 5 mg/cm^2 will be used. 15 μm of Au will be used in order to stop the beam and the recoils.

The beam-time estimation was performed for the ^{96}Zr(^{13}C,3nγ)^{106}Pd reaction given the beam current is $I_c = 20$ pnA and the detector efficiency is approximately 1% for the HPGe part and 1% for the LaBr$_3$:Ce part of the detector array. Given that the states of interest are placed at about 2-3 MeV above the ground state, where the de-exciting transitions have intensity of approximately 5% of the $2_1 \rightarrow 0_1$ transition, 59.3 counts/sec in singles are expected. In order to obtain clean time spectra triple coincidences are needed. Then, the expected yield in a 8 hour shift is 205 counts. Thus, a statistically significant time spectrum for one of the nuclei will be obtained in 5 days. This estimation is consistent with our previous experiments with similar reactions we performed at Magurele.

Given the cross-sections for ^{94}Zr(^{13}C,3nγ) and ^{96}Zr(^{13}C,3nγ) reactions are $\sigma \approx$ 300mb and $\approx$ 200mb respectively **two weeks of beam-time are requested** in order to measure the half-lives of the low-lying negative-parity states in ^{102,104,106}Pd.

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