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Short note

Beta decay of neutron-rich ^{118}Rh and the lowest excited states in ^{118}Pd

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Abstract. Beta decay of a refractory isotope ^{118}Rh produced in symmetric fission and mass separated by the ion guide technique has been applied for the study of low-lying excited states of ^{118}Pd. The yrast band in ^{118}Pd has been observed up to a 6^+ state and the lowest states of the asymmetric γ-band have been identified. The measured half-life of ^{118}Rh is (300 ± 60) ms. The systematics of the excited states in neutron-rich Pd-isotopes implies the saturation towards an $O(6)$ symmetry at $N = 70$.

PACS. 27.60.+j $90 \leq A \leq 149$ – 23.20.Lv Gamma transitions and level energies – 21.10.Re Collective levels

1 Introduction

Structure of neutron-rich Pd-isotopes has recently gained renewed theoretical interest [1–4], although the experimental progress has been slower since the first breakthrough experiments at IGISOL [5]. Transitional Ru, Pd and Cd nuclei provide an interesting test bench for various nuclear models due to rapid changes in magnitude and type of deformation. Cd isotopes are often treated as a vibrator [6] while Ru isotopes clearly exhibit softness against asymmetric γ-deformation. Pd-isotopes link these two structures and show the characteristics of both.

During the last few years intensities of refractory ion beams available at IGISOL have become high enough for pushing the experiments further away from stability. Here we report on a study, where the beta decay of ^{118}Rh was characterised for the first time leading to identification of low-lying excited states of the yrast and gamma-bands in ^{118}Pd.

An experimental information on the level structure of Pd-isotopes was extended up to ^{116}Pd and ^{117}Pd by applying the IGISOL technique [5,7]. An in-beam experiment employing spontaneous fission of ^{254}Cf resulted in identification of few new excited states of the yrast band in even $^{110-116}$Pd [6,8]. Recently, information on the ground-state band of ^{118}Pd was published [9] utilising the information of the beta-decay study of the present work. An existence of ^{118}Rh was recently verified both at MSU and GSI, employing projectile fission of ^{238}U [10,11]. However, neither one of these experiments could provide any spectroscopic information.

2 Experimental methods

The ^{118}Rh isotope was produced in proton-induced fission of ^{238}U. The intensity of the 50 MeV H_2^+ beam varied between 10–20 μA. The 7.9 mg/cm^2 thick ^{nat}U-target was tilted to 7 degrees with respect to the beam axis resulting in an effective target thickness of 65 mg/cm^2. The average production rates were about 900 and 8500 ions/s for ^{118}Pd and ^{118}Ag, respectively, and the yield of ^{118}Rh was estimated as 50 ions/s. The extracted ion beam was mass separated and transported to a movable tape [12]. The implantation position was viewed by three Ge-detectors in a close geometry. Two plastic scintillator detectors for observing beta particles were placed in opposite sides of the implantation point. The measurement was cycled so that each of the 1s-collection periods was followed by the 1.5 second beam-off decay period. During the decay period, both the primary and the separator beams were turned off. Before each new collection period the implantation tape was moved 20 cm to transport long-lived daughter activities away. Any gamma-gamma or beta-gamma coincidence, excluding those where beta and gamma were observed by the detectors in the same side of the source, provided a trigger for the acquisition. All events were

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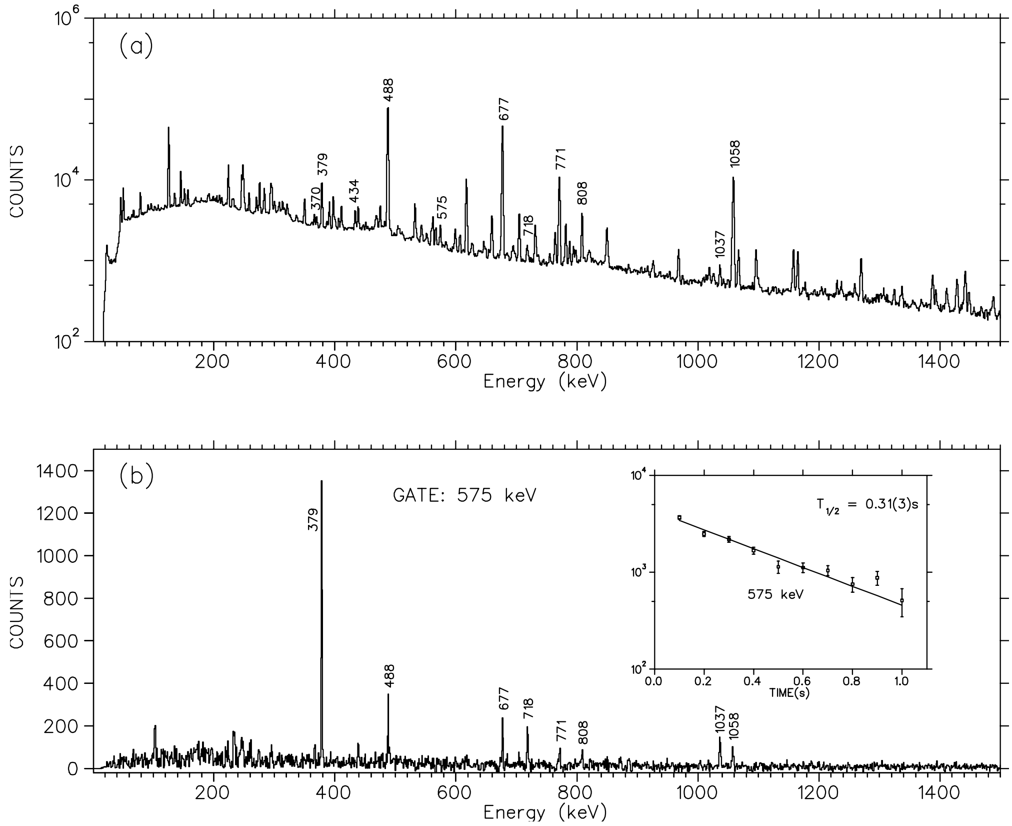

Fig. 1. (a) The beta-gated gamma-spectrum in $A = 118$ collected during the first 500 ms in the implantation period. The total collection time was 45 hours. (b) A gamma-spectrum gated by the 575 keV, ($4^+ \rightarrow 2^+$) transition. An inset shows the time behaviour of the 575 keV transition. The transitions with energy 488, 677, 771, 808 and 1058 keV are the strongest γ-rays measured in the $A = 118$ isobaric chain. They are from the decay of ^{118}Ag which is the main source of contamination for identifying the ^{118}Rh decay.

tagged with the real time and the time within each measurement cycle. The latter provided the means to identify observed transitions according to their half-lives and to measure beta-decay half-life.

3 Experimental results

The analysis of the data involved several steps to carefully eliminate any spurious sources for a new activity. Any unknown short-lived gamma-activity was used as a candidate for transitions in ^{118}Pd-isotope. The most obvious one was a 575 keV transition, which was found to decay very fast and which could not be explained by any other means. It was soon realised that a 379 keV transition, which exists also in the decay of ^{118}Pd contained a short-lived component. These two transitions were also observed in coincidence with each other. Thus they provided a starting point for further coincidence gating used to construct the level scheme of ^{118}Pd. Transitions assigned to the β-decay of ^{118}Rh are listed in table 1. The intensities of the individual transitions were extracted from the beta-gated gamma-spectra, except in those cases where overlapping transitions could not be separated. The beta-gated gamma-spectrum recorded in 45 hours is shown in fig. 1(a). Figure 1(b) presents the gamma-spectrum obtained in coincidence with the 575 keV transition. The deduced level scheme of ^{118}Pd is shown in fig. 2. Spin and parity assignments are based on the decay properties of each state and the systematics of known neutron-rich Pd-isotopes. The yrast band up to a 6^+ state is proposed based on the coincidence and intensity relations of the 379, 575 and 718 keV transitions. The energies of the assigned excited states follow smoothly the level systematics in neutron-rich Pd-isotopes, as shown in fig. 3. Additional transitions were placed in the level scheme according to their coincidence relations.

Following the systematics of lighter neutron-rich Rh-isotopes one would expect at least two beta-decaying states in ^{118}Rh, one with a spin of 1^+ and another with a spin between 4 and 10. Due to their similar high beta-decay energy, beta-decay half-lives of these states are expected to be similar. It turned out that the best transition to extract the half-life was the 575 keV transition with the measured half-life of (310 ± 30) ms. Since the 575 keV transition de-excites the 4^+ state, the half-life extracted is related to the beta decay of a high-spin isomer. The half-life of a low-spin isomer could not be reliably extracted from the 379 keV transition due to the overlap with the beta decay of ^{118}Pd and the fact that it is fed via a

Table 1. List of γ-rays assigned to the decay of ^{118}Rh.

E_γ [keV]	I_γ	I_i	I_f	Coincident γ-transitions
369.6(1)	10(2)	3_1^+	2_2^+	379,434
379.0(1)	100	2_1^+	0_1^+	370,434,575,718,804,1037
433.6(1)	15(2)	2_2^+	2_1^+	370,379
574.6(1)	42(5)	4_1^+	2_1^+	379,718,1037
717.5(2)	18(3)	6_1^+	4_1^+	379,575
803.6(2)	12(2)	3_1^+	2_1^+	379
812.6(2)	9(3)	2_2^+	0_1^+	370
1036.5(2)	6(3)	(4)	4_1^+	379,575

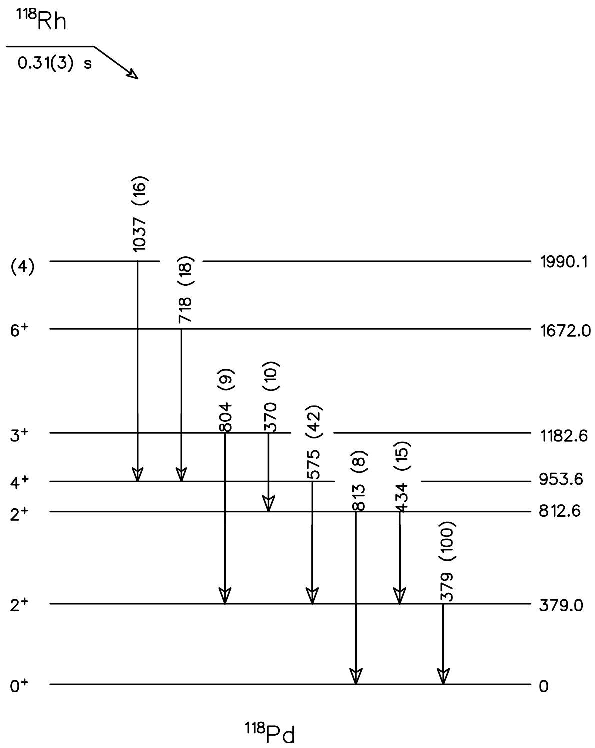

Fig. 2. Level scheme of ^{118}Pd.

high-spin cascade. Since the beta-feeding to the ground state of ^{118}Pd could not be measured in this experiment, we cannot deduce reliable $\log ft$ values for ^{118}Rh decay.

4 Discussion

The results of this work provide new insight on the structure of heavy Pd-isotopes beyond the known "plateau" of the yrast energies between $N = 64$ and $N = 68$. Earlier studies have shown that the energy minimum of the yrast states occurs at $N = 68$ ($A = 114$). This is next to the middle of the shell, located at $N = 66$. Our new results show a smooth transition towards higher excitation energies. This implies the decrease of the collectivity when the neutron shell $N = 50$–82 starts to fill after the mid-shell. The systematics of the energy ratios, $E(4^+)/E(2^+)$ and $E(6^+)/E(2^+)$ studied in references [5, 8] for even $^{110-116}$Pd implies an increasing trend up to ^{116}Pd. This was interpreted as a transition from a $SU(5)$-vibrator to an $O(6)$-γ unstable symmetry. The data for ^{118}Pd shows that the $O(6)$ symmetry has reached its maximum at $A = 116$ ($N = 70$) and a sudden transition back to the $SU(5)$ symmetry occurs between $A = 116$ and $A = 118$ as shown in fig. 4.

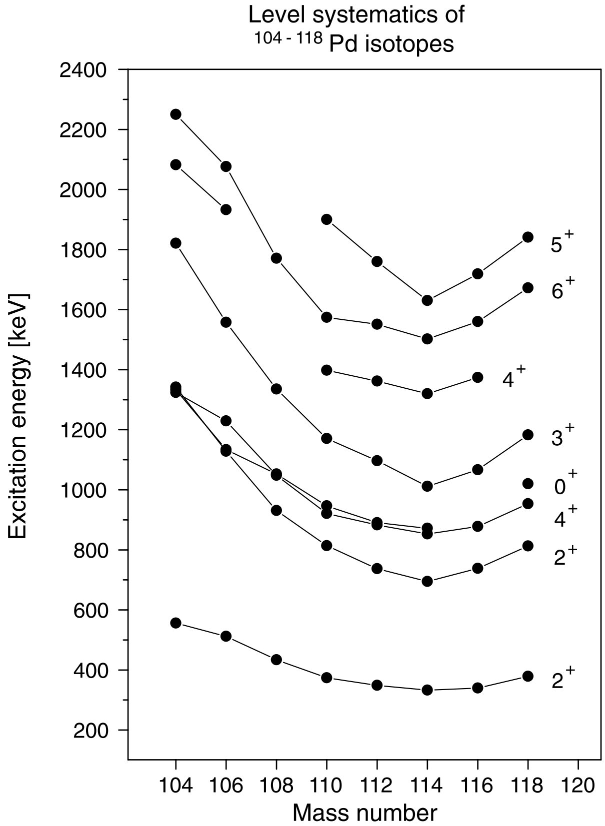

Fig. 3. Systematics of excited states in neutron-rich even-even Pd-isotopes.

The beta-decay schemes of even $^{110-116}$Rh isotopes have a unique strong feeding of the states above the neutron pairing gap. Äystö *et al.* [5] suggested that the allowed beta decay of a high-spin member of the $\pi g_{9/2} \otimes (\nu d_{5/2}, \nu d_{3/2}, \nu s_{1/2}$ or $\nu h_{11/2})$ multiplet via the $\nu g_{7/2} \rightarrow \pi g_{9/2}$ transition would lead two-quasineutron states, while the low-spin 1^+ member of the same multiplet populates the low-lying collective states, namely the 0^+ ground state and the excited 0^+ and 2^+ states. The two-quasineutron states in Pd can be identified due to their strong feeding in beta-decay. This provides a tool to obtain information on the pairing interaction, as shown by Capote *et al.* for neutron-rich $A \approx 100$ nuclei [13]. It is of importance to search for these states very far from stability where other means to learn about the pairing interaction are scarce. For example, binding energy data is often missing or highly inaccurate to make conclusions

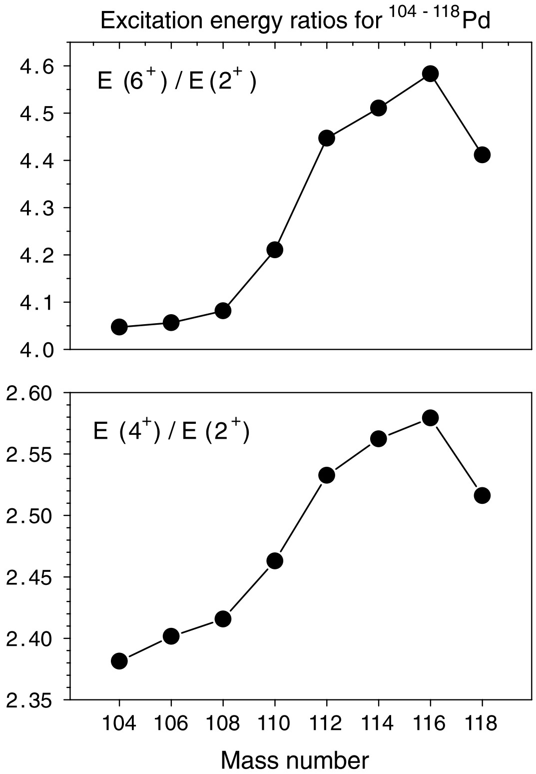

Fig. 4. Energy ratios of excited states in neutron-rich Pd-isotopes.

about the pairing gap and thus about the strength of the pairing interaction. However, no clear evidence was obtained for such a decay pattern in ^{118}Rh contrary to decays of $^{110-116}$Rh. Nevertheless, the coincidence relations suggest the well-separated state around 2.5 MeV. Position of these states agrees well with an extrapolated energy of two-quasiparticle states in Pd, which are observed to decrease in energy when neutron pairs are added. Future studies to search for 2qp-structures in neutron-rich Pd and Ru isotopes are needed.

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