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NUCLEAR STRUCTURE STUDY OF ^{104}Pd BY COULOMB EXCITATION AT THE WARSAW HEAVY ION LABORATORY*

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Low-lying excited states of ^{104}Pd were investigated by means of Coulomb excitation using the ^{32}S beam. Gamma-ray spectra resulting from the deexcitation of these levels were measured with the EAGLE gamma-ray spectrometer at the Heavy Ion Laboratory, University of Warsaw. The first three excited states above the ground state up to 6^+ level were populated alongwith the low-lying non-yrast states. Excitation of the 3^- state at 2194 keV energy was also observed.

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1. Introduction

Level structures of even–even stable Pd isotopes are considered as being examples of quadrupole vibrational spectra [1]. Nevertheless, Coulomb excitation investigations of $^{106-110}$Pd have demonstrated that these nuclei

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show rather complicated structures [2, 3], which may be explained as a result of the interplay of collective and single particle effects. In particular, the relatively low-lying 0^+ states in this isotopic chain may arise from collective excitations, but some of them were suggested as built from the single-particle intruder states [4]. Moreover, proton-pair excitations across the $Z = 50$ shell were demonstrated to account for the presence of low-lying non-vibrational configurations in $Z \approx 50$ nuclei [5].

Experimental data on electromagnetic structure of ^{104}Pd are surprisingly scarce in the contrary to the experimental information available for the neighbouring, heavier, even–even Pd isotopes [2]. No lifetime measurements have been performed for ^{104}Pd and for Coulomb excitation studies only very light beams of alpha and oxygen were used. Transition probabilities in ^{104}Pd are, therefore, known from basically one measurement. In 1986, Luontama *et al.* performed Coulomb excitation experiment with 44 MeV ^{16}O beam on 90% enriched ^{104}Pd target of 20 mg/cm^2 thickness and the γ rays were detected in $\gamma\gamma$ coincidence mode by using an annular NaI(Tl) detector and a Ge(Li) detector [6]. The probability of measuring multi-step Coulomb excitation was lower as compared to the modern techniques of particle–gamma coincidence measurements with particle detectors at backward angles [7]. The data were analysed partially using GOSIA code [8], but matrix elements were mainly extracted with Winther–de Boer code [9], so their magnitudes and, in particular, uncertainities are less reliable because the gamma-ray intensities calculation and error estimation are implemented in GOSIA code only.

It should be noted that ^{104}Pd targets are nowadays often used in exotic beams Coulomb excitation experiments *e.g.* [10, 11]. The high excitation probability of the first 2^+ state together with known $B(\mathrm{E2};\, 2^+_1 \rightarrow 0^+_1)$ value and relatively simple level scheme make ^{104}Pd a good choice as a target in Coulomb excitation experiments aimed to study the properties of the exotic nuclei. In such experiments, the absolute excitation cross sections of the investigated projectile–nucleus are determined by normalising to the target excitation. The obtained results, *i.e.* values of the transition probabilities in the exotic nuclei excited on the ^{104}Pd target, depend on the precise knowledge of the electromagnetic structure of the latter.

Low-energy Coulomb-excitation measurements can bring important information on the electromagnetic structure of ^{104}Pd *viz.* the spectroscopic quadrupole moments of excited states and/or transition probabilities between not only the excited yrast states but also non-yrast ones. With this motivation, the present experiment was performed at the Heavy Ion Laboratory, University of Warsaw. First preliminary results of this work are presented in this paper.

2. Experimental details

The 97% isotopically enriched ^{104}Pd target of 2 mg/cm^2 thickness was bombarded with a 91 MeV ^{32}S beam from the Warsaw cyclotron. The beam energy for the present projectile–target combination was chosen to fulfil the Cline's criteria [12] of "safe energy" to ensure the purely electromagnetic interaction between the colliding nuclei. The EAGLE [13] spectrometer equipped with 15 HPGe detectors coupled with PIN-diode array [14] was used for the detection of γ -rays de-populating Coulomb-excited states. PIN-diodes of 0.5×0.5 cm^2 active area were mounted in a compact spherical chamber of 5 cm radius at $\sim$ 120–170 degree backward angles with respect to the beam direction and are shown in Fig. 1. The coincidence window of 200 ns was created for collecting the time-coincident particle–gamma data. The data were collected in particle–gamma coincidence mode for 5 days.

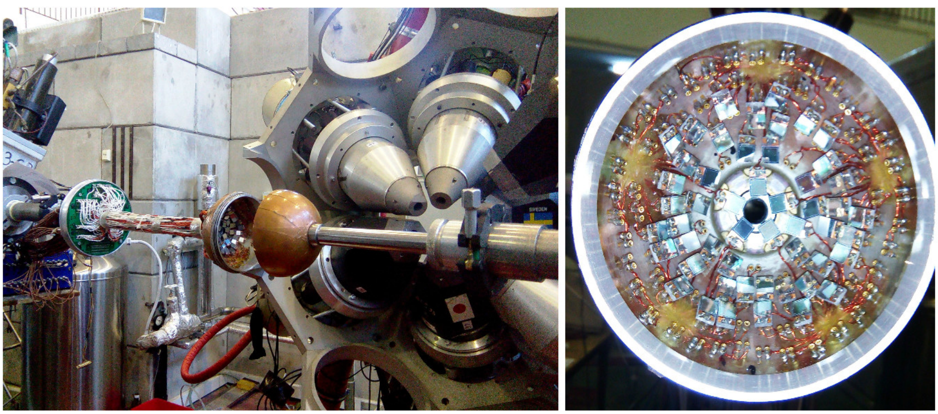

Fig. 1. Open view of the PIN-diode array mounted at the centre of the EAGLE spectrometer [13] (left). PIN-diodes of 0.5×0.5 cm^2 active area mounted inside the scattering chamber [14] (right).

3. Results and analysis

The γ-ray spectrum was created by using the particle–gamma coincidence condition. Positions of detectors were determined precisely (with uncertainty of 1 mm for PIN-diodes and 5 mm for HPGe detectors) to perform the Doppler corrections of de-excited γ rays and less than 1% FWHM was obtained after Doppler corrections. Timing gates were applied for each individual combination of germanium and PIN-diode detectors to create prompt and random gamma-ray spectra. An example of timing spectrum is presented in Fig. 2. Prompt and random time peaks were observed at a distance of 70 ns in the time spectra for the pulsed structure of the beam delivered

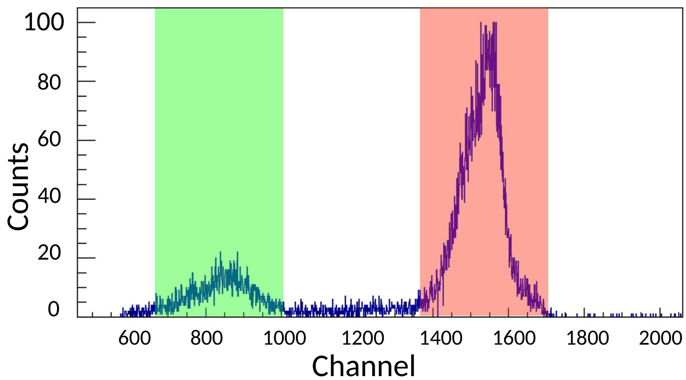

Fig. 2. Particle–γ coincidence timing spectrum for individual PIN-diode-HPGe combination for the pulsed beam from the Warsaw cyclotron. Gates on the random and prompt peaks are shown by the shaded regions from channel numbers 650–1000 and 1350–1700, respectively. The spectrum is calibrated with 0.1 ns per channel.

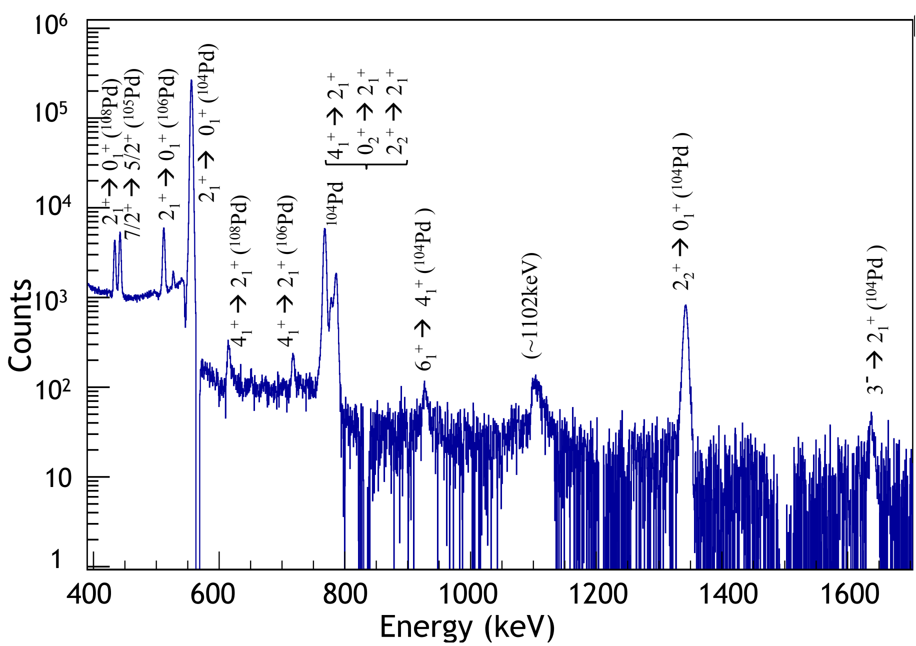

Fig. 3. Total background-subtracted and Doppler corrected gamma-ray spectrum resulting from present Coulomb excitation experiment of ^{104}Pd with 91 MeV ^{32}S beam. The 1102 keV peak was not interpreted within the known level schemes of palladium isotopes; its interpretation will be subject of the further analysis.

by the Warsaw cyclotron. The random time-gated gamma-ray spectrum, normalized to the intensity of the 511 keV gamma-annihilation peak, was subtracted from the prompt time-gated gamma-ray spectrum. The prompt gated and random subtracted gamma-ray spectra for individual PIN-diode and germanium detector were summed over all the germanium and PIN-diodes to get the total statistics, as it is shown in Fig. 3.

In Fig. 3, the background subtraction is overestimated in the case of random events related to the wrongly Doppler corrected gamma-rays emitted from ^{104}Pd with an incorrect particle correlation. But for those events, the low energy recoiled palladium nuclei were stopped in the target, so the energies of gamma rays are separated from properly Doppler corrected ^{104}Pd lines. In the present experiment, states up to 6^+ in the ground state band along with the low-lying non-yrast bands were populated. The decay of the 6^+ state at 2250 keV was not observed in earlier Coulomb excitation experiments performed with lighter beams, *e.g.* ^{16}O [6]. In the gamma-ray spectrum, we also observed the 1638 keV gamma-ray transition which was interpreted as a decay of 3^- level at 2194 keV [6, 15].

Gamma-ray transitions for other stable Pd-isotopes (^{105,106,108,110}Pd) were also observed as an isotopic contamination in the target. The low-energy part of the ^{104}Pd level scheme that was populated in the present experiment, together with the observed electromagnetic transitions, is shown in Fig. 4.

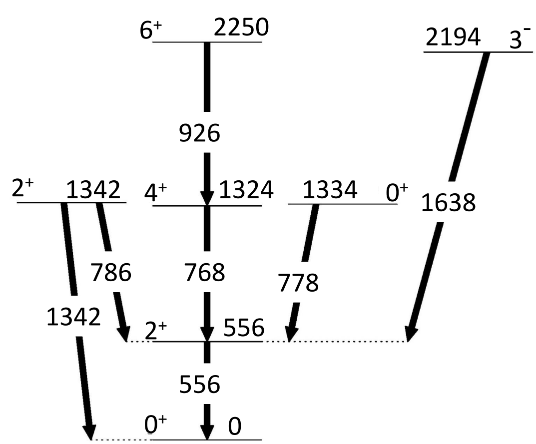

Fig. 4. Low-energy part of the level scheme of ^{104}Pd showing γ-ray transitions observed in the present Coulomb excitation experiment. All energies of γ-ray transitions and levels are given in keV.

4. Summary and outlook

The 6^+ state at 2250 keV was populated by the Coulomb excitation for the first time. Additionally, low-lying non-yrast states were also observed along-with the 3^- state. To describe electromagnetic structure of ^{104}Pd, further analysis aiming the determination of matrix elements will be performed by using the least square fitting code, GOSIA [8]. The main goal of the experiment is to determine the quadrupole moment of the ${2_1}^+$ in ^{104}Pd. The fact, that the third 2^+ state at energy 1794 keV was not observed in the present experiment supports the very low $B(\mathrm{E2}; 2_3^+ \to 0_1^+)$ value estimated in [6] and the final results will take this into account.

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