Spectroscopy of Two Quasi-Particle States in ^{230}Pa*

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Abstract

The completely unknown spectrum of excited states of the odd-odd nucleus ^{230}Pa was studied employing the one-neutron transfer reaction ^{231}Pa(d,t)^{230}Pa at a beam energy of 22 MeV. The excitation energy and the cross section were measured for in total 81 states below 1.4 MeV. Level assignments of these states are based on a semi-empirical model and comparison with theoretical predictions based on DWBA calculations for the cross sections. The ground state of ^{230}Pa is assigned to be a 2^- state. A sequence of four rotational states is measured on top of the ground state. The band head of the first excited rotational band is found at an excitation energy of 48 keV. The energy difference of these two bands is compared to similar states in other N=139 isotones, especially the directly neighbouring odd-mass isotone ^{229}Th. Here the two neutron orbitals $5/2[633]_n$ and $3/2[631]_n$ cause an extremely low-lying isomeric state. Also at higher energies the band head energy, the rotational parameter, the K-quantum number and the Nilsson configuration are established for the new states in ^{230}Pa.

A first time spectroscopic investigation of ^{230}Pa was motivated by the missing data for odd-odd nuclei which are still scarce and often incomplete. This is especially true for well deformed actinide nuclei, because experimental work is difficult in that region due to the very limited number of target materials available and the competition of all experimental approaches with high fission cross sections.

Moreover a unique constellation of nuclear levels in the N=139 actinide isotones results in remarkably small energy differences between nuclear ground states and first excited states. The smallest known excitation energy in a nucleus is found in ^{229}Th. Here the first excited state is located only a few eV above the ground state. The same Nilsson orbitals that are responsible for the tiny energy gap in ^{229}Th also play an important role in the neighboring ^{230}Pa isotone.

The reaction ^{231}Pa(d,t)^{230}Pa was used to produce and study the ground state and excited states of the isotope ^{230}Pa. The radioactive ^{231}Pa target was bombarded by a polarized deuteron beam of 22 MeV. The outgoing tritons were analysed by the Munich Q3D magnetic spectrometer which was set to nine angles between 5° and 45°.

Particular attention was given to the energy calibration of the spectrometer, in order to obtain reliable and precise energy information for the completely unknown excitation spectrum of ^{230}Pa. Two independent in-beam calibration measurements employing the reactions ^{234}U(d,t)^{233}U and ^{230}Th(d,t)^{229}Th were performed with the same settings of the magnetic spectrometer. The spectra of ^{233}U and ^{229}Th were calibrated over the full relevant energy range with well-known peaks from these isotopes. Moreover, a wealth of new states was identified in ^{233}U. Spin and parity assignments for 33 states were determined by comparison with results from DWBA calculations. Based on these assignments and energy systematics, the observed states were sorted into rotational bands. The Nilsson configurations of the bands are identified by examining the population strengths within each band. Two rotational bands with Nilsson configurations 1/2[501] and 3/2[501] could be identified for the first time. Results of these measurements are published in [1].

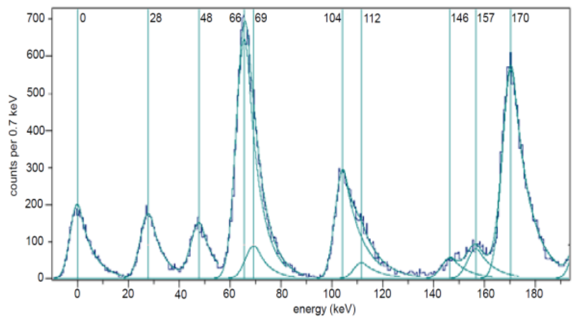

Figure 1: Low energetic part of the excitation spectrum of the odd-odd isotope ^{230}Pa measured at an angle of 20°.

The one-neutron transfer reaction ^{231}Pa(d,t)^{230}Pa is sensitive to two-quasiparticle states with the proton occupying the same Nilsson configuration as in the target nuclei. Therefore, states with the proton configuration 1/2[530] were detected in this measurement. After a thorough analysis of all measured spectra, 81 states below the excitation energy of 1.4 MeV were identified.

A successful attempt was made to identify rotational bands in ^{230}Pa. As guidance for these assignments predictions for band-head energies, rotational parameters and cross sections were utilized, which are based on experimental and theoretical values from neighbouring nuclei. Finally, suggestions for 12 rotational bands are obtained by using: *(i)* the predictions from a semi-empirical model, *(ii)* the energy systematics within a rotational band, *(iii)* the number of observable band members is consistent with cross sections from DWBA calculations, *(iv)* the Gallagher-Moszkowski GM splitting and the difference between rotational parameters yield consistent decoupling parameter, *(v)* in the case of K=0 bands comparable rotational parameters for the even and odd partial bands are required.

The suggested scheme of levels and rotational states is the result of a thorough analysis of all possibilities and gives a picture consistent with the available predictions and expectations [2]. The Fig. 2 summarizes the proposed bands. For each rotational band the band-head energy and the rotational parameter is determined. The K-quantum numbers and the Nilsson configurations are established. Six empirical values for GM splitting and two values for Newby shifts are obtained from the extracted level scheme. To confirm these tentative assignments, more experimental and theoretical work is required; especially an independent experimental determination of spin and parity values is desirable. In summary, the new data is a significant extension of our knowledge of odd-odd isotopes in the actinide region, especially in the light of the generally scarce data at the fringes of the actinide region. Hopefully, more theoretical and experimental work is inspired by this exploratory investigation in this area.

The very small energy difference of the eV isomer in ^{229}Th was not reproduced. The smallest energy difference between the $5/2^+$ and $3/2^+$ state was 46 keV in ^{230}Pa and is in agreement with typical excitation energies from neighbouring nuclei [3]. The necessity for a detailed understanding of the underlying nuclear structure remains an important prerequisite for the right description of the peculiar configuration at ^{229}Th. The results on ground state properties and excited states in ^{230}Pa provide new experimental input and will contribute to a refined theoretical understanding of this intriguing region of the chart of nuclei.

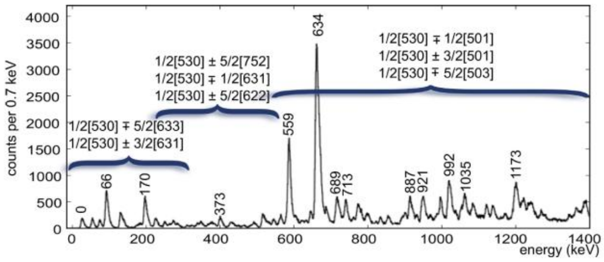

Figure 2: Full spectrum of ^{230}Pa with energy ranges for the expected rotational bands. Several prominent peaks are labelled.

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