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First observation of excited states in ^{192}Po

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γ rays following the ^{160}Dy(^{36}Ar,4n)^{192}Po reaction have been identified by employing a high-transmission gas-filled separator in recoil decay tagging measurements. The deduced level scheme reveals a flattening of the energy systematics, when going towards the neutron midshell indicating that the deformed intruder structures have become yrast. [S0556-2813(96)50212-8]

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The microscopic origin of quadrupole collectivity at low-excitation energies in neutron midshell nuclei near the $Z=50$ and $Z=82$ shell closures is not well known. In some of these nuclei, deformed intruder states coexist with nearly spherical normal states [1], while for example in the even-mass Cd nuclei the intruder structures clearly play a role in generating low-lying quadrupole phonon states [2]. These intruder structures are usually associated with two-proton excitations across the main shell gap, but recently the importance of deformation driving high-j neutron orbitals in these states has also been pointed out [3–5].

In this respect, the Po nuclei with two protons outside the $Z=82$ shell closure form an interesting series of isotopes. The α- and β-decay studies by the Leuven group [6–9] strongly support the view that the abrupt drop of level energies in light even-mass Po isotopes is due to proton $4p$-$2h$ intruder configurations while in recent calculations by the Rutgers group [4,5] this behavior is quite well reproduced by taking into account neutron orbitals, especially the $i_{13/2}$.

In order to resolve the ambiguities discussed above, it is crucial to extend the Po energy-level systematics towards the neutron midshell. However, as a consequence of strong fission competition, the fusion-evaporation reaction channels for populating the midshell Po nuclei become very weak and, therefore, special triggering methods are needed.

In the present work we describe in-beam γ-ray studies of ^{192}Po [10] by using the recoil decay tagging method [11,12]. A recent determination of the half-life of its α-decaying ground state gave a value of 33.2(14) ms [9]. No excited states in ^{192}Po have been identified before our work.

The experiments were performed at the Accelerator Laboratory of the University of Jyväskylä (JYFL). A beam of 178 MeV ^{36}Ar ions from the JYFL K130 cyclotron was used to bombard a 70% enriched 500 μg/cm^2 thick ^{160}Dy target. The ^{192}Po nuclei of interest were produced via the $4n$-evaporation channel. Prompt γ rays from the target were detected by the DORIS array consisting of 9 TESSA type [13] Compton suppressed Ge detectors in a truncated dodecahedron frame. The efficiency of the array is about 0.6% at 1.3 MeV.

The gas-filled recoil separator RITU [14] was used to separate fusion-evaporation residues from the dominant fission background. RITU is a charge and velocity focusing device, especially designed for collecting recoiling fusion-evaporation residues with high efficiency. Recoils were implanted into an 80×35 mm Si strip detector covering about 70% of the recoil distribution at the focal plane. The estimated total efficiency for the ^{192}Po recoils was 25% and about 50% of the α particles emitted by them were detected. The position sensitivity of the Si detector enabled the recoils to be correlated with their subsequent α decays. The detector was divided into 10 mm wide vertical strips each having a position resolution of about 0.4 mm. At a typical beam in-

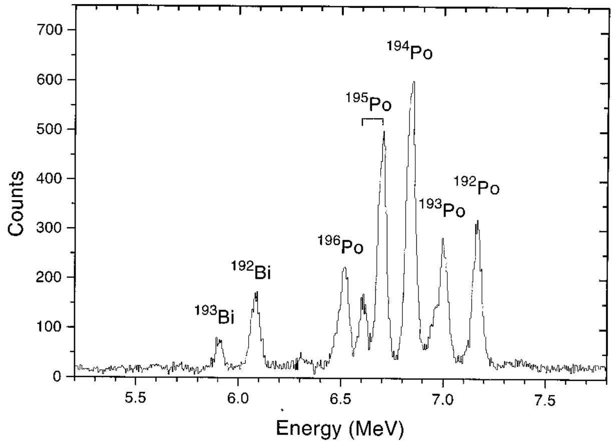

FIG. 1. An energy spectrum of α particles observed within a 200 ms time interval after the detection of a recoil at the same position in the Si strip detector. A recoil-γ coincidence was also required.

tensity of 20 particles nA, limited by the Ge counting rates, the total counting rate in the Si strip detector was about 150 counts/s.

Signals from the Si strip detector for the energy, position as well as the detection time of the recoils and α particles were recorded. Individual γ-ray energies and γ-γ coincidence events were recorded when they occurred in coincidence with detected recoils.

In the data analysis, the events corresponding to the observation of a recoil together with the subsequent α decay at the same position within a maximum time interval of 200 ms were selected. A resulting projected α particle energy spectrum with an additional recoil-γ coincidence condition is shown in Fig. 1. The assignments of the α peaks in this figure are based on the known α-decay energies. The highest-energy peak is associated with the decay of ^{192}Po. An estimate of about 10 μb was obtained for the ^{160}Dy(^{36}Ar,4n)^{192}Po reaction cross section from the singles counting rate of ^{192}Po α particles. The half-life extracted from the projected time spectrum for the ^{192}Po α events is consistent with the earlier value [9]. In spite of the 200 ms

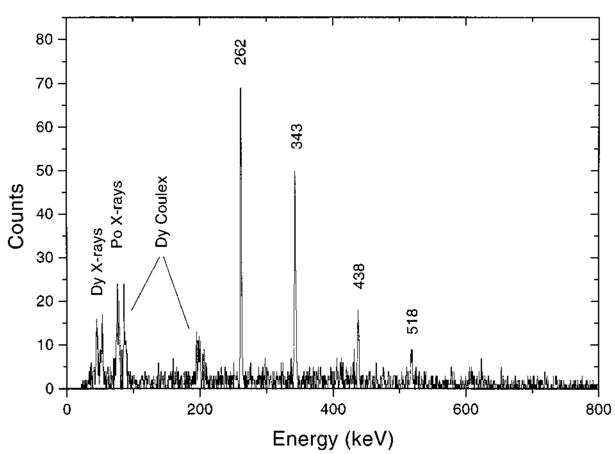

FIG. 2. A singles γ-ray energy spectrum gated with fusion-evaporation residues and tagged with the ^{192}Po α decay.

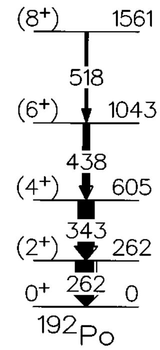

FIG. 3. Deduced level scheme of ^{192}Po. The arrow widths are proportional to the measured intensity. Spin assignments are based on systematics.

time interval, the α peaks from the other Po isotopes in Fig. 1 are still intense, mainly because these nuclei are produced with much higher cross sections than ^{192}Po in ^{36}Ar induced reactions on the contaminating heavy Dy isotopes in the target.

A gate on the ^{192}Po α peak of Fig. 1 yields a recoil gated γ-ray spectrum of Fig. 2 with new transitions at 262, 343, 438, and 518 keV. Based on their intensities and the available level-energy systematics, we tentatively identify these lines with an $E2$ cascade of a ground state band in ^{192}Po as shown in Fig. 3. This interpretation is also supported by the recoil gated α tagged γ-γ coincidence spectra.

The low-energy systematics for even-mass $^{192-210}$Po isotopes including our new data for ^{192}Po are shown in Fig. 4. The low-lying levels of the closed-shell ^{210}Po nucleus are

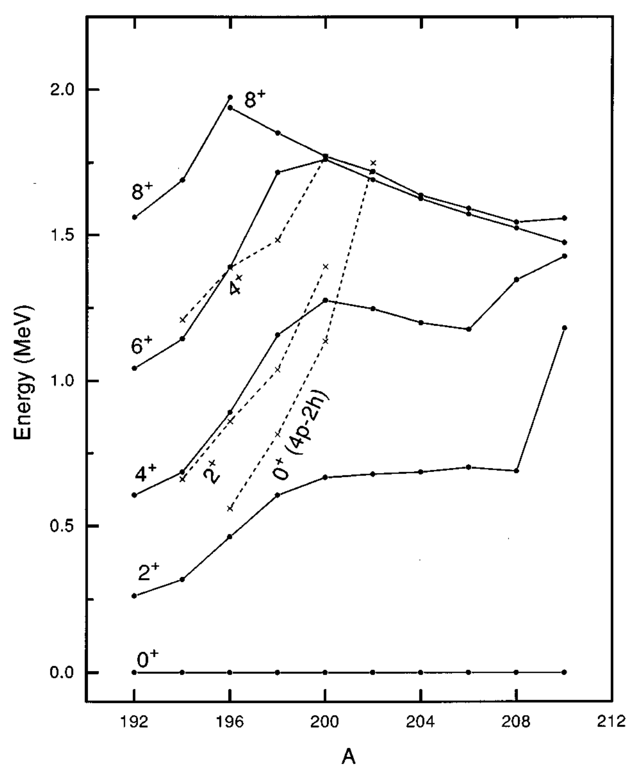

FIG. 4. Level systematics for the even-mass $^{192-210}$Po isotopes taken from Refs. [4,15–22] and the present work.

mainly formed by the proton $h_{9/2}^2$ multiplet. In the even $^{198-208}$Po isotopes, neutron-hole orbitals are released for 2^+ and 4^+ broken pairs resulting in an increase of collectivity and a decrease of energy of the yrast 2_1^+ and 4_1^+ states. The level-energy behavior is rather smooth until at ^{196}Po, a drop of energies of the 2_1^+, 4_1^+, and 6_1^+ states are observed [16,17]. Second excited 2^+ and 4^+ states were also found in ^{196}Po and ^{198}Po and associated with proton $4p$-$2h$ intruder configurations [17].

Based on their more detailed in-beam γ-ray studies, Bernstein *et al.* have shown that ^{196}Po and ^{198}Po actually have features of quadrupole vibrational nuclei [4]. Their view is that instead of the $4p$-$2h$ proton configurations, the neutron hole orbitals, especially $i_{13/2}$, are responsible for the sudden energy changes. Continuation of the steep drop of energies of the positive parity levels up to 10^+ in ^{194}Po was revealed in a recent in-beam γ-ray study at the Argonne FMA by Younes *et al.* [15]. Their conclusion is that the vibrational character of heavier Po isotopes appears to be present also in ^{194}Po.

Very valuable information for the low-energy 0^+ and 2^+ states in light even-mass Po isotopes has been extracted in α- and β-decay studies by the Leuven group [6–9]. They have discovered an excited 0^+ state in $^{196-202}$Po (Fig. 4) and identified it as the proton $4p$-$2h$ intruder. Moreover, from the extracted hindrance factors and $E0$ transition properties, they deduce that with decreasing neutron number, the intruder and normal states mix strongly and, therefore, the proton intruder configurations are responsible for the abrupt decrease of level energies. Based on a simple mixing calculation, they estimate that the intruder contribution in the 2_1^+ state increases with the decreasing neutron number up to 88% in ^{194}Po and in the 0_1^+ ground state up to 29% in ^{194}Po and 58% in ^{192}Po.

Our new results for ^{192}Po reveal signs of the flattening of the energy systematics when going towards the neutron midshell. A similar behavior has been observed in even-mass Pt nuclei where it has been interpreted as evidence for a ground state intruder configuration [1]. That the observed band structure in ^{192}Po is indeed based on an intruding ground-state structure different from those for heavier Po isotopes is also indicated by the mixing calculations discussed above [9]. It should be noted that based on the Nilsson-Strutinsky type of calculations, May *et al.* [23] predicted that in ^{192}Po an oblate deformed minimum becomes the ground state. As in the case of the Pt nuclei [1], the relatively high rotational parameter associated with the 2_1^+-0_1^+ energy spacing in ^{192}Po can be explained by the mixing of the 0_1^+ and 0_2^+ states with a consequent depression of the 0_1^+ ground state. This is also in agreement with the above-mentioned mixing calculation result and the α-decay properties of ^{192}Po [9].

In spite of the remarkable agreement with the proton $4p$-$2h$ intruder picture, a possible role of deformation driving neutron orbitals in the behavior of yrast states of light Po nuclei cannot be ruled out. Younes *et al.* [5] have shown that the ^{192}Po level energies can be quite well reproduced without any proton-intruder configurations.

As a summary, the spectrum in Fig. 2 shows that the use of a high-transmission recoil separator in recoil decay tagging experiments renders in-beam γ-ray spectroscopy possible at the few microbarn cross-section level for heavy nuclei close to the proton drip line. We have identified, for the first time, excited states of ^{192}Po and have assigned them as a deformed intruder ground-state band. Whether this band is due to the proton $4p$-$2h$ configurations or the neutron configurations or due to both of them, remains an open question.

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