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The discovery of a prolate-oblate-spherical shape triple of spin 0^+ states in the atomic nucleus ^{186}Pb

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Two excited $J^\pi=0^+$ states in ^{186}Pb populated in the α-decay of ^{190}Po have been identified through α-particle/conversion electron coincidences in an experiment at the velocity filter SHIP. The parent ^{190}Po nuclei have been produced in the ^{142}Nd(^{52}Cr,4n)^{190}Po complete fusion reaction. α-particle energies and branching ratios have been measured and hindrance factors were deduced. The observed states have been interpreted as the band heads of the known prolate and (yet unobserved) oblate rotational bands in ^{186}Pb.

1. INTRODUCTION

The fundamental excitations in many-fermion systems remain one of the most exciting subjects of today's physics. In even-even atomic nuclei, pair breaking, vibrations and

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rotations generally form the low-lying excitation spectrum. However, for specific numbers of protons and neutrons, a subtle rearrangement of only a few nucleons among the orbitals at the Fermi surface can result in a different elementary mode: a macroscopic shape change [1,2]. Many examples of coexisting configurations have been observed in the vicinity of the closed shells that arise from the excitation of pairs of neutrons and/or protons from the closed shell core [1,2]. A particularly interesting case is the variety of shapes which are exhibited by neutron-deficient lead isotopes. Indeed, for even-mass lead nuclei close to the mid-shell at N=104 calculations predict *three* differently shaped configurations, coexisting at relatively low excitation energy: a spherical ground state associated with the Z=82 shell closure, an oblate π(2p-2h) proton configuration with a moderate deformation of about $\beta_2 \approx -0.15$ and a more strongly deformed prolate configuration ($\beta_2 \approx 0.25$), predicted at N$\leq$106 [3,4], which can be associated with an excitation of four or even six protons (π(4p-4h) or π(6p-6h) configurations) from the core.

Recent α-decay and in-beam studies provided evidence for multiple shape coexistence in ^{188}Pb [5–8] and in ^{190}Pb [9,10]. In particular, in ^{188}Pb, low-lying 0^+ band head states, associated with the oblate π(2p-2h) and prolate π(4p-4h)/π(6p-6h) configurations have been identified [5–7], while at higher excitation energies a few high-K isomeric states were found, which were interpreted as states belonging to different coexisting configurations [8].

The aim of this study was to extend the investigations to the more neutron-deficient ^{186}Pb nucleus, where similar coexisting phenomena were expected from the potential-energy surface calculations [3,4].

2. EXPERIMENTAL RESULTS

We have identified for the first time in a nucleus (^{186}Pb) three different shapes (spherical - oblate - prolate) as the *lowest* three states in the energy spectrum [11]. The parent ^{190}Po nuclei were produced in the ^{142}Nd(^{52}Cr,4n)^{190}Po complete fusion reaction, studied with the velocity filter SHIP [12] at the UNILAC heavy-ion accelerator (GSI, Darmstadt). Nuclei of interest after separation were implanted into a position- sensitive silicon detector (PSSD), where their subsequent α decays were measured, see Fig. 1.

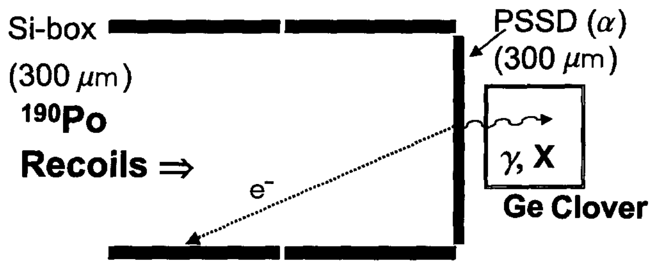

Figure 1. Schematic view of the detection system used in this study. Shown are PSSD, backward silicon detectors and Ge Clover detector. See text for details.

In front of the PSSD six similar silicon detectors were mounted (Si-box), facing the PSSD, which were used to detect conversion electrons in prompt coincidence with α-particles. A 4-fold segmented Ge Clover detector was installed behind the PSSD to record prompt α-X and α-γ coincidences. The whole set-up has been optimized to observe fine structure in the α decay that leads, as studied for the heavier even-even Pb nuclei [13], to the identification of low-lying 0^+ band heads, which will decay predominantly by E0 conversion electron transitions to the ground state. Further details on the experimental method can be found in [11,14].

Fig. 2a shows a part of the α spectrum recorded in the PSSD within 12 ms after the recoil implantation. The α line at 7533(10) keV represents the ground state to ground state α transition of ^{190}Po decaying with a half-life of 2.45(5) ms, an improved value compared to literature.

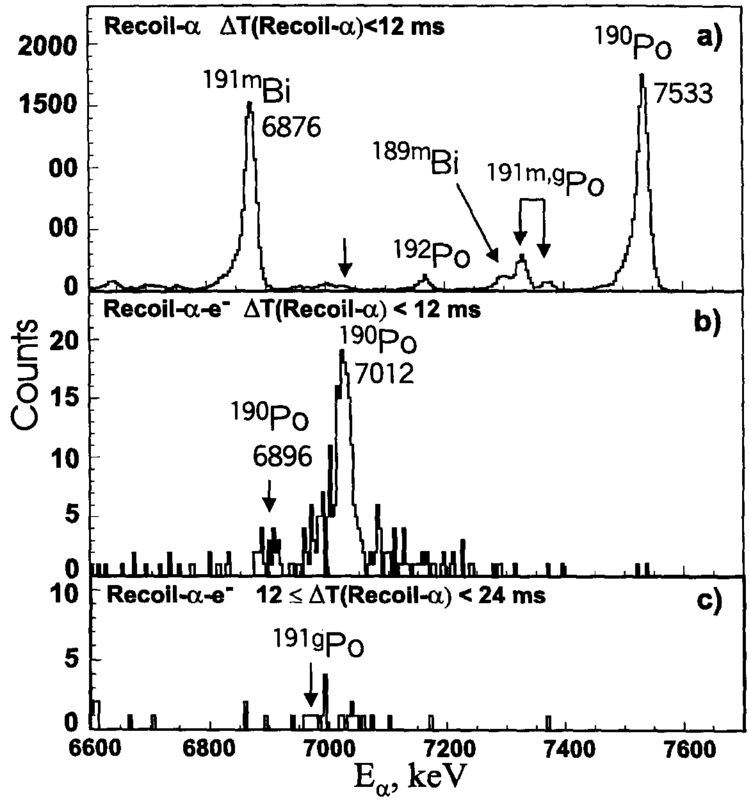

Figure 2. a) Part of the α spectrum recorded in the PSSD within 12 ms after the recoil implantation. Some peaks are labeled with the α-decay energy and isotope they belong to; b) The same as a) but in a prompt coincidence with conversion electrons, registered in the backward Si detectors; c) The same prompt electron condition as in b) but now with α events that are registered between 12 and 24 ms after the implant.

Fig. 2b shows the same α-spectrum as in Fig. 2a but in a prompt coincidence with conversion electrons, registered in the backward Si detectors. Two α-lines (7012(20) and 6896(20) keV) can be seen in this spectrum. Fig. 2c shows a spectrum as in Fig. 2b but now α events are registered between 12 and 24 ms after the implant. As can be seen in Fig. 2c these peaks are almost completely decayed in the time interval of 12 ms, thus proving short-lived character of these activities. The half-life of the 7012 keV line was deduced as 2.6(3) ms while for the 6896 keV line an upper limit of 5 ms for the short-living component is obtained. By comparing the coincidences of the 7012 and 6896 keV α lines with electrons, X- and γ-rays, the only valid conclusion is to assign the two lines as fine structure lines in the α decay of ^{190}Po feeding excited levels in ^{186}Pb that subsequently decay by E0 conversion electron emission to the ground state, see Fig. 3.

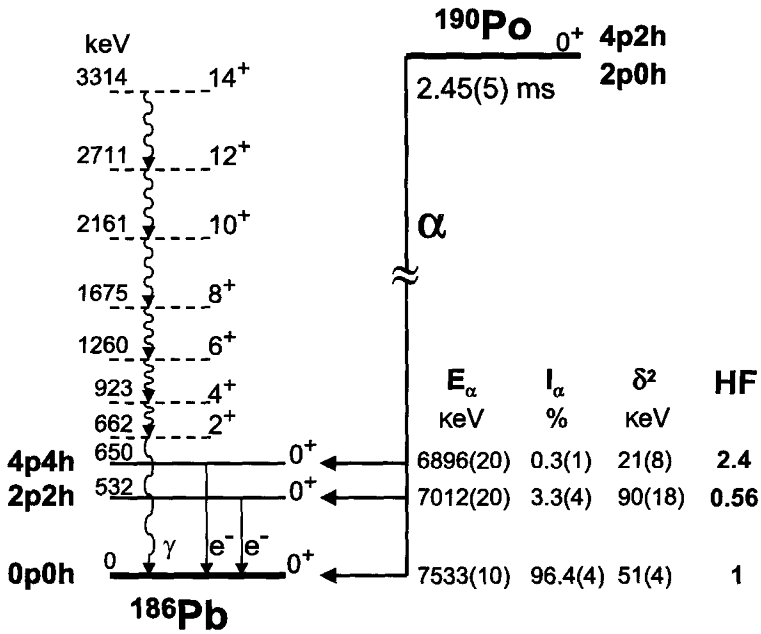

Figure 3. Decay pattern of ^{190}Po and the level scheme of ^{186}Pb. Indicated are α-decay energies E_α, intensities I_α, reduced α-widths δ^2 and configuration assignments. The known prolate rotational band ($I^\pi=2^+ - 14^+$) is shown by dashed lines [15,16].

From the reduced α-decay widths δ^2 of $\Delta L = 0$ transitions, information on the structure of the configurations involved in the connected states can be obtained [13]. This method has been used to show that the ground state of ^{186}Pb is spherical, as are all heavier even-even Pb nuclei. The ground states of even-even Po nuclei with A>196 exhibit a spherical 2p proton configuration. However, owing to the rapid lowering in energy of deformed 4p-2h proton configurations, the ground states of the lighter even-even Po nuclei, from

^{196}Po on [9,13] develop a mixed character of 2p and 4p-2h configurations (with $\approx$70% of the latter in the ground state of ^{192}Po [5,17]). The reduced widths in the α-decay of ^{190}Po (see Fig. 3), as well as in the case of ^{192}Po [5,6], corroborate this superposition and show that the decay to the 0p-0h spherical ground state in ^{186}Pb is much slower than the decay to the first excited 0^+ state indicating that the ground state of ^{190}Po is mainly the deformed 4p-2h configuration and that the first excited 0^+ state in ^{186}Pb has a multiparticle-multihole character.

Based on the energy systematic of the oblate bandheads in the heavier Pb isotopes [13], on the extrapolation of the 0^+ bandhead energy starting from the higher spin members of the prolate band in ^{186}Pb (see Fig. 3) and on the reduced α-widths, we identify the 0^+ state at an excitation energy of 532 keV as the oblate state and the 0^+ state at an excitation energy of 650 keV as the prolate state. Both of these levels are below the first excited 2^+ state, which is at 662 keV.

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