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Short Note

The decay of the new neutron-rich isotope ^{217}Bi

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Abstract. Exotic, neutron-rich proton-induced spallation products of ^{232}Th and ^{238}U obtained from the PS Booster ISOLDE facility have been investigated by γ-γ, α-γ coincidence and spectrum-multiscaling measurements. A new method for the reduction of isobaric contamination enabled to study the unknown region beyond ^{208}Pb for the decay chain $A = 217$. A new isotope ^{217}Bi with a half-life of 98.5 ± 0.8 s was discovered and its β-decay studied. For the first time, a half-life value of 1.53 ± 0.03 s for the α-decay of ^{217}Po was measured.

PACS. 23.20.Lv γ transitions and level energies – 23.60.+e α decay – 27.80.+w $190 \leq A \leq 219$ – 29.30.Kv X- and γ-ray spectroscopy

1 Introduction

This paper presents the results on the β-decay of a new exotic neutron-rich isotope ^{217}Bi and on the α-decay of its daughter nucleus ^{217}Po. It is a continuation of our efforts undertaken at the ISOLDE (CERN) facility to investigate the extremely neutron-rich, exotic nuclei located beyond the doubly closed shells nucleus ^{208}Pb [1,2].

2 Experimental procedure

Two separate experiments were carried out at the PS Booster ISOLDE facility in CERN in which the neutron-rich nuclei of mass $A = 217$ were investigated. In the first one, ions from a hot-plasma ion source were mass-separated in a regime called "pulsed release method" [1] to reduce the isobaric contamination. These measurements were complemented by the use of resonant laser ionization of bismuth atoms in the second experiment.

In the first experiment a thick 55 g/cm^2 target of ^{232}ThC$_2$ combined with a hot-plasma ion source [3] was bombarded with pulsed beam of 1 GeV protons with an intensity of 3×10^{13} particles per pulse. The PS Booster accelerator operated in a sequence of 14.4 seconds long super cycle consisting of 12 equidistant pulses of which a fixed number was sent to the ISOLDE target. After the proton beam impact, a waiting time of 200 milliseconds before releasing the radioactive species from the ion source was implemented. It considerably reduced unwanted isobaric contamination of short-living actinides. The detector setup, data acquisition operation and all other details of this experiment were presented in [2]. Here only the

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specific settings for mass $A = 217$ will be described. Two different combinations of the beam-on and beam-off times were used further in the $A = 217$ isobaric chain measurements. For investigation of short-living activities a one super cycle long (14.4 s) implantation with 4 proton pulses was followed by a beam-off period of the same length. The single multispectra were recorded in a 8×1 s cycle. There was also a beam-on period of 10 super cycles with 6 proton pulses per cycle and 15 super cycles long beam-off period, with the single spectra recorded in a 8×26 s multiscaling cycle.

In the second experiment, the pulsed-release method was used together with the Resonant Ionization Laser Ion Source (RILIS) [4,5] to achieve chemical selectivity of the ion source. The investigated activity was produced by spallation of a UC_x target (50 g/cm^2 of ^{238}U and about 10 g/cm^2 of carbon) by a 1.4 GeV proton beam with intensity of 3×10^{13} protons per pulse. In each super cycle of 16.8 s (14 equidistant pulses) there were from 8 to 11 proton pulses sent to the ISOLDE target. In the multispectra cycle the implantation and decay periods were 16 super cycles long and the single spectra were recorded in a 8×32.5 s multiscaling cycle.

In both experiments the isotopes of interest were implanted onto a movable collection tape. The tape was moved after each implantation and decay (or beam-off) cycle to remove long-lived activity from the measurement point. Moreover, in the second experiment the tape was transporting the activity from the collection point to a lead-shielded decay location. At the collection point there were one silicon (area = 450 mm^2) and one germanium detector (relative efficiency = 70%) to measure α-γ coincidences. Data were collected only in coincidence mode by an independent acquisition system. The set-up at the decay point consisted of three germanium detectors for recording γ radiation and one plastic scintillator to detect β-particles. Events were recorded in both coincidence and single data modes.

The energy and efficiency calibration procedures are described in the simultaneously submitted paper [6].

3 Experimental results

3.1 The beta-decay of ^{217}Bi

The most exotic decay observed in the $A = 217$ mass chain was the β^- disintegration of the newly discovered ^{217}Bi isotope. The strong α-decay branch of ^{217}Po (appearing as a daughter of ^{217}Bi decay and coming in the first experiment also directly from the separator) enabled the observation of γ transitions accompanying the β^--decay of ^{213}Pb. The decay of ^{213}Pb will be published elsewhere [7]. Coincidence relations for the γ lines in ^{217}Po are shown in table 1 and a resulting decay scheme is given in fig. 1. In table 1 there are some coincident γ transitions belonging to ^{205}Rn decay. They are due to the presence of a γ line with energy of about 265.8 keV, which is only partially resolved from the 264.6 keV transition in ^{217}Po. Long-living isotopes of Rn diffuse through the separator, contaminating the set-ups. Some excited states in ^{217}Po were previously observed in the α-decay of ^{221}Rn, see fig. 1 [8,9]. The level schemes of ^{217}Po presented in both papers are the same and consist of two levels: 254.2 and 264.7 keV. Due to the exotic character of the investigated Po isotope and consequently very low intensities of the observed

Table 1. Energies, relative intensities and coincidence relations for γ-rays observed in the decay of ^{217}Bi. Superscript ^{a} indicates transition belonging to ^{205}Rn. The γ-intensities were not corrected for summing. The intensities marked with "c" were extracted from coincidence spectra.

E_γ (keV)	I_γ^{rel}	Coincident γ lines
254.1(1)	27.9(12)	447.4, 841.5, 889.9
264.6(1)	100(6)	436, 465.7^a, 675.9^a, 889.9, 1017
436(3)	4.7(14)c	
447.4(7)	2.0(3)	
841.5(18)	3.4(6)	254.1
889.9(6)	5.7(7)	264.6
1017(1)	4.0(13)c	264.6

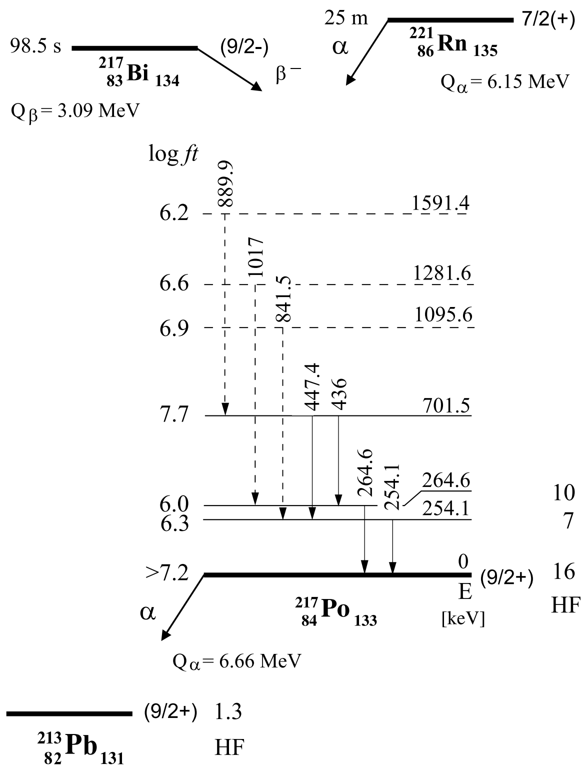

Fig. 1. The energy levels fed in the β^--decay of the ^{217}Bi and α-decay of ^{217}Po. The hindrance factors for ^{221}Rn α-decay come from [9]. The spin of the ^{217}Bi g.s. is from [10] and its Q_β value from [11]. The characteristics of ^{221}Rn, Q_α for ^{217}Po and spin of the ^{213}Pb g.s. are taken from [12]. Unobserved γ-rays feeding the levels at 254.1 and 264.6 keV will increase the adopted log ft values.

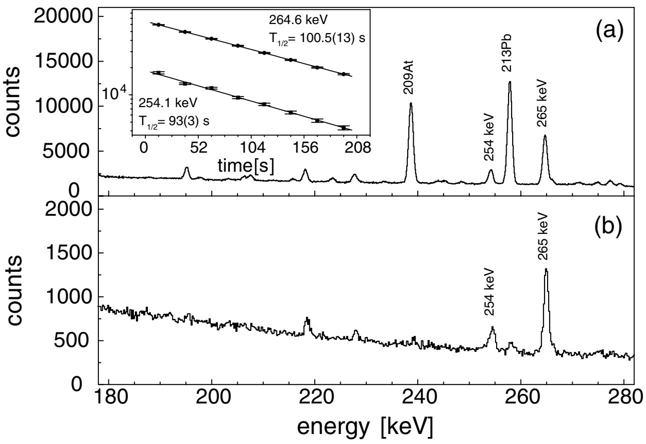

Fig. 2. (a) The first 26 second time subgroup of the single spectrum recorded with a LEGe detector for $A = 217$. Fitted decay curves for the marked γ transitions are shown in the inset. Data from the standard ISOLDE ion source [3]. (b) The first 32.5 second time subgroup of the single spectrum recorded with a LEGe detector with the laser ion source set to bismuth. Data from the RILIS experiment.

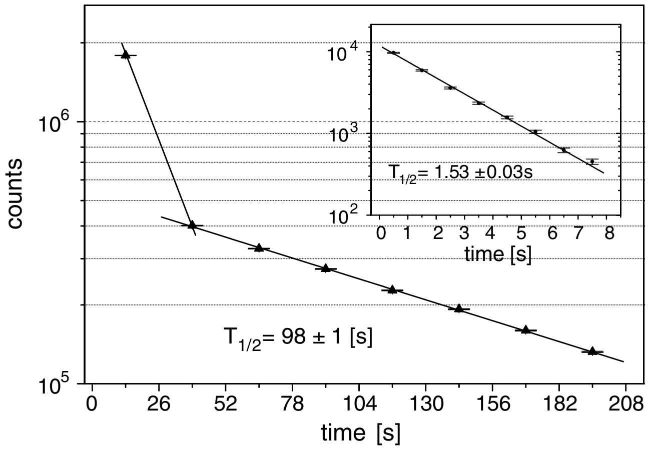

Fig. 3. The numbers of counts for the 6543 keV α line in the consecutive 26 second long time subgroups of α detector single spectrum. For comparison, decay of the same line is shown for the 8×1 s cycle. Data from the standard ISOLDE ion source.

transitions only a limited extension of the level scheme in ^{217}Po was possible.

Using the single spectra recorded in eight consecutive 26 second time subgroups it was possible to determine the half-lives of the γ lines de-exciting energy levels in ^{217}Po. A single spectrum from the LEGe detector showing the 254 and 265 keV lines together with their decay patterns is presented in fig. 2. These γ lines are the only sufficiently intensive lines to enable their half-life determination. Two slightly different half-life values were found: 100.5 ± 1.3 s for 264.6 keV and 93 ± 3 s for 254.1 keV transition. Another way to determine the half-life of ^{217}Bi is through the α-decay of the ^{217}Po daughter. A value of 98 ± 1 s (see fig. 3 and sect. 3.2) is deduced. Combining the three half-life values yields 98.5 ± 0.8 s as the adopted half-life of ^{217}Bi.

3.2 The alpha-decay of ^{217}Po

According to [9], the ground state of ^{217}Po decays for 100% by α emission to the ground state of ^{213}Pb emitting alpha-particles with an energy of 6537 ± 4 keV. Our energy is 6543 ± 4 keV.

The decay of this α line during 8 consecutive seconds made it possible to deduce for the first time the half-life of ^{217}Po: 1.53 ± 0.03 s (see inset in fig. 3). Previously, an upper limit of 10 s was known for this half-life [9]. Figure 3 shows also the time behavior of the ^{217}Po α-decay for a long-time cycle which is governed by the time behavior of the ^{217}Bi mother. A half-life fit through the time units 2 to 8 gives 98 ± 1 s.

3.3 Estimation of the beta ground-state feeding

For the long-time cycle activity was collected on the Mylar tape for 144 s (see sect. 2) and then emitted radiation was registered for 208 s. In the second subgroup of the multispectrum (from the 27th to the 208th second of the beam-off period) ^{217}Po is produced only by the decay of the much longer living ^{217}Bi —see fig. 3. As a consequence, each β^--decay of ^{217}Bi is followed by a ^{217}Po decay with the emission of a 6543 keV α-particle. Using this fact it is possible to estimate the population of the levels in ^{217}Po by comparing the total intensity of the γ transitions accompanying ^{217}Bi β-decay to the intensity of the alpha-particles emitted in the ^{217}Po α-decay. In the comparison only the dominant 254 and 265 keV γ transitions were taken into account. The evaluated level feedings (see fig. 4) enabled the calculation of $\log ft$ values. The results are presented in fig. 1. As the $\log ft$ values are partially based on differences in γ-ray intensities, unobserved γ-rays could increase the adopted $\log ft$ values.

In [9] the authors suggest probable multipolarities for the 254 and 265 keV transitions as $E2$ and $M1$, respectively. The comparison between γ-ray intensities (see table 1) and intensity (equal to 146 ± 15) of the 6543 keV α transition suggest none or limited ground-state feeding, depending on the theoretical conversion coefficients assumed for the γ-rays. It also limits the possibilities for the multipolarities of the 254 keV and 265 keV transitions to $E1$, $E2$ or $M1$ for the 254 keV and $E1$, $E2$ for the 265 keV transition. The $M1$ character for the 264 keV transitions is hardly probable because of its too high internal conversion coefficient.

4 Discussion

The most exotic, odd isotope of bismuth ^{217}Bi with half-life of 98.5(8) s was observed for the first time. According to the shell model, spin and parity of its ground state should be specified by the unpaired proton occupying the $1h_{9/2}$ orbital above the $Z = 82$ closed shell. The isotope ^{217}Bi decays via β^- transitions to

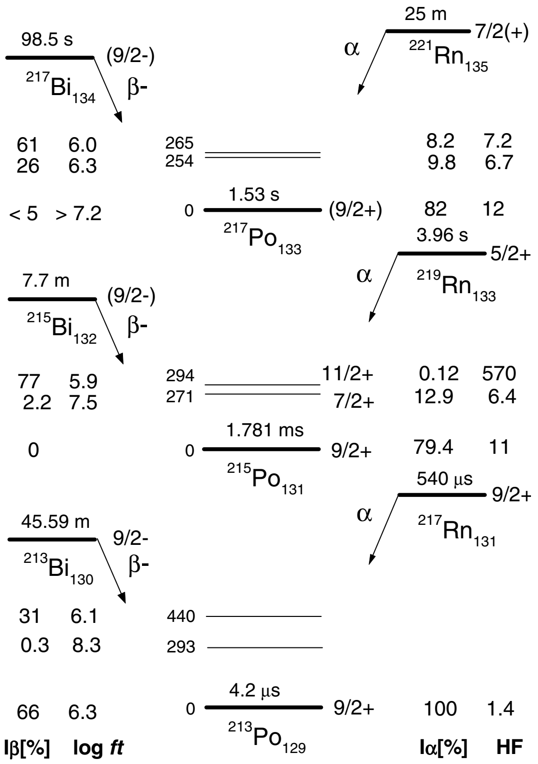

Fig. 4. The ground and two lowest excited states in ^{213,215,217}Po isotopes fed in the β^--decay of ^{213,215,217}Bi and α-decay of ^{217,219,221}Rn, respectively. The α-intensities (I_α) and the hindrance factors (HF) for ^{221}Rn decay are from [9]. The I_β and $\log ft$ values for ^{217}Bi β^--decay come from this work and for ^{215}Bi β^--decay from [6]. The half-life of ^{217}Bi, suggested spin assignment of ^{217}Po g.s. and its half-life are from this work. The spin assignments of ^{217,215}Bi ground states are extrapolated from the systematics. Other values are taken from [12].

excited states in ^{217}Po, which were observed formerly through the α-decay of the $7/2^{(+)}$ ground state of ^{221}Rn. On the basis of these α-decay data spin and parity of the ^{217}Po ground state was postulated by Liang *et al.* as $11/2^+$, the 254 keV excited level as $7/2^+$ and with more uncertainty the 265 keV level as $9/2^+$ [9]. However, our half-life value of ^{217}Po gives a hindrance factor for the α-decay toward the ground state of ^{213}Pb of 1.3. This indicates that the ground states of ^{217}Po and ^{213}Pb are very similar. From our new decay study of ^{213}Pb there is no experimental evidence that the ground state of ^{213}Pb is not $9/2^+$, based on the $\nu\, g_{9/2}$ configuration (see discussion in the forthcoming paper [7]). The arguments developed by Liang *et al.* [9] for the $11/2^+$ assignment of the ground state of ^{217}Po are based on the differences in α-decay hindrance factors in the decay of ^{221}Rn (see fig. 4). Starting from the Rn isotopes, we expect the collective effects may influence more the properties of the nuclei disturbing the systematics of the hindrance factors. Thus we suggest $9/2^+$ assignment for the ground state of ^{217}Po and, tentatively, $7/2^+$, $11/2^+$ spins and parities, respectively, for the levels 254 keV and 265 keV. It is clear from fig. 4 that the feeding patterns are changing dramatically when going from ^{213}Bi to ^{217}Bi. Further experimental studies and dedicated theoretical work are needed to explain why for heavier bismuth isotopes (starting from ^{215}Bi) the feeding to the Po ground state is disappearing.

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