Beta decay half-life of ^{231}Ra

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Abstract

The low-energy structure of ^{231}Ac has been investigated by means of γ , conversion electrons, γ - γ and γ - e^- spectroscopy following the β^- -decay of ^{231}Ra . Here, we report on the precise determination of the ^{231}Ra β -decay half-life.

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Since the observation of low-lying $K^\pi = 0^-$ bands in doubly even radium nuclei [1] the possibility that some nuclei can be described by mean field with broken reflection symmetry has been considered [2]. Numerous experimental and theoretical discoveries were made in the 1980s providing extra evidence of reflection asymmetric octupole deformation around $A = 225$ [3]. Many of these nuclei have been studied at ISOLDE in β -decay experiments [4]. An important feature of static octupole deformation in odd- A nuclei is the observation of parity doublets, i.e. rotational bands with the same intrinsic parameters and spins, but opposite parity lying close in excitation energy.

The study of the upper border of this octupole deformed region is of great relevance in order to understand the interplay of octupole and quadrupole collectivities and to reveal the exact mechanism by which the octupole deformation disappears in the presence of a well-developed quadrupole field. Experimentally one should observe an enhancement of the $B(E1)$ transition strength for the parity pair partner bands. With this aim the IS322 collaboration at CERN carried out a systematic investigation of the heavy transitional Fr–Th nuclei. These experiments provided the first information on the absolute values of $B(E1)$ in this octupole transitional region. Relatively large $B(E1)$ -rates have been measured indicating the presence of octupole correlations in ^{227}Fr , ^{229}Ra and ^{229}Th . Much weaker but still noticeable are the correlations in the heavier isotopes ^{231}Ra and ^{231}Th . Here, the study of their isobar ^{231}Ac is reported, for which only scarce information exists [5–7].

The structure study of ^{231}Ac is based on two sets of measurements performed at the PSB-ISOLDE(CERN) on-line mass separator. In both experiments a 1 GeV proton beam bombarded a $\text{UC}_2\text{-C}$ target, producing via spallation reactions the $A = 231$ isobars. In the first experiment, a W-surface ionizer was used inhibiting the ionization of ^{231}Fr . In the second experiment, the use of a Ta(Re) surface ion source of lower working function favoured the production of ^{231}Fr . Therefore the excited structure of ^{231}Ac was populated directly from the β -decay of ^{231}Ra in the first run with an estimated production of 4×10^3 atoms per μC , and through the decay chain of $^{231}\text{Fr} \rightarrow ^{231}\text{Ra} \rightarrow ^{231}\text{Ac}$ in the second where the production was similar, 5.6×10^3 atoms per μC [8]. The produced ions were accelerated and mass-separated before being collected onto a magnetic tape transport system which connected two independent but simultaneously operated measurement stations. The radioactive beam was deposited in the centre of the specially designed *fast timing station* to measure the half-life of excited states in the nano- and pico-second range by the Advanced Time Delayed (ATD) $\beta\gamma\gamma(t)$ method [9]. The effective dynamic range of the β -gated $\gamma\gamma$ coincidences was 25–1500 keV. The study of the $\gamma\gamma$ coincidences allowed the determination the level scheme. Several half-lives of states in ^{231}Ac could be derived, and the deduced $B(E1)$ rates are used to infer the possible presence of octupole correlations, which is discussed in detail in [10]. The radioactive sample was transported a metre away by the tape to the *conversion electron station* for γ identification and conversion electron measurements.

Table 1. γ -rays following the β -decay of ^{231}Ra and used to determine its half-life.

E_γ (keV)	I_γ (%)		$T_{1/2}$ (s)	
	This work	[7]	This work	[7]
41.27(5)	8.5(15)	—	96.9(45)	—
47.45(5)	3.3(3)	—	110.2(92)	—
54.29(5)	88(7)	44(10)	104.9(26)	93(18)
77.97(6)	33(3)	—	111.9(26)	—
87.66(5) ^a	80(7)	100(15)	101.5(30)	98(6)
90.86(5) ^a	124(11)	164(15)	103.0(28)	98(6)
129.76(7)	5.2(4)	—	95.9(53)	—
192.00(8)	13.5(10)	—	108.2(56)	—
204.95(12) ^b	107(19)	93(6)	105.9(20)	108(11)
232.71(9)	21.0(8)	—	115.3(42)	—
254.57(10)	14.5(8)	—	102.3(36)	—
403.03(15)	26.5(15)	—	90.7(38)	—
409.89(10)	100(5)	100(12)	99.9(23)	100(10)
456.19(15)	59.5(25)	59(7)	99.0(27)	109(13)
462.38(15)	47(2)	43(6)	107.0(43)	115(19)
469.23(15)	80(4)	75(6)	108.2(33)	118(13)
512.85(10)	58(6)	—	112.2(29)	—

^a $K_{\alpha 2}$ and $K_{\alpha 1}$ components of the Ac x-ray.^b Doublet. The relative intensity of the two components are deduced from coincidence data and given in [10].

It consisted of a mini-orange electron spectrometer, a γ telescope and a β detector. The γ telescope is a compact device which allows for detection of γ - and x-rays with an effective dynamic range of 6–2500 keV in singles and from 11 keV in coincidences. The conversion electron spectrum runs from 20 keV up to 500 keV with a reasonable efficiency of 1.0–0.4%. A detailed description of the setup is given elsewhere [8]. Multipolarities of 26 transitions have been established via γ -e⁻ spectroscopy [10].

Measurements in the two stations were conducted simultaneously with a time cycle chosen to enhance the nucleus of interest in the isobar chain. In the first experiment, the cycles were chosen of 17 and 190 s and in the second one of 26 and 200 s to enhance the decay of ^{231}Fr ($T_{1/2} = 17.5$ s) and ^{231}Ra ($T_{1/2} = 103$ s), respectively. The results on the decay of ^{231}Ra to ^{231}Ac are based on the data collected with the long cycles, divided in eight subgroups of 23.75 and 25 s, respectively. For each γ -line the intensity determined in each subgroup versus the time depends on the half-life of the parent.

Prior to this work six γ -lines were known in ^{231}Ac [7] and a value of the β -decay half-life of ^{231}Ra of 103(3) s was obtained. In our work the intensity ratio of the γ -lines between the short and long cycles has helped to identify the low intensity γ -transitions. The most intense γ -transitions were assigned to the β -decay of ^{231}Ra by comparing their temporal behaviour to that of the Ac x-rays. In 44 transitions the decay curves give a half-life value within 15% of the nominal one. The most intense ones have been used to deduce the β -decay half-life of ^{231}Ra and are listed in table 1 together with the values existing in the literature [7]. Although the subgroups

Figure 1. Temporal evolution of ^{231}Ac γ -rays at 54.29, 77.97 and 409.89 keV and the $K_{\alpha 1}$ x-ray of Ac.

chosen in this work (~ 25 s) are very different from the one of Hill *et al* [7] (120 s) the half-life values agree well. The energies of the γ -lines are the weighted mean of the values obtained in the two independent experiments. In both cases, the energies and intensities of the γ -transitions are deduced from the second station favouring at low energies the values obtained from the planar detector of the γ -telescope due to the high resolution of this detector (0.4 keV at 14 keV and 0.8 keV at 122 keV). Figure 1 shows the temporal evolution of some of these γ -rays. For comparing the variation of intensity in the different subgroups of the 90.9 keV, $K_{\alpha 1}$ x-ray is shown. The weighted mean of the half-lives obtained for the different γ -transitions is 104.1(8) s in good agreement with the previous value of 103(3) s but much more precise. Detailed information on the spectroscopy of ^{231}Ac can be found in [10].

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