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Low-lying levels in ^{119}Xe

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ABSTRACT

The decays of ^{119m}Cs and ^{119g}Cs to ^{119}Xe have been studied on mass separated samples, using $\gamma-$ray and internal conversion electron measurements. Several new low-lying levels have been established in the ^{119}Xe level scheme. Half-life evaluations for ^{119m}Cs and ^{119g}Cs have been revisited. The results are compared with other experimental data known in light odd-mass xenon isotopes and with calculations performed in the frame of the multi-shell interacting boson-fermion model.

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1 INTRODUCTION

The present study is part of a program developed at the ISOLDE facility to investigate the $\beta-$decay schemes of light cesium isotopes [1], [2]. The experiments have been focused on the ^{119}Xe low-lying level scheme populated in the β/EC decays of ^{119m}Cs and ^{119g}Cs for which a few results have been previously reported [3]. This approach is very similar to the one already applied for the ^{121m,g}Cs to ^{121}Xe beta decays [4].

Spin and parity of the ^{119}Xe ground-state are definitely known to be $\mathrm{I}^{\pi} = 5/2^{+}$ [5]. A first partial level scheme for the lowest excited states fed by beta decay in ^{119}Xe has been reported to stand a comparison with the ^{117}Xe isotope [6]. From in-beam studies of ^{119}Xe a wealth of data is available at intermediate - and high-spin states [7], [8], [9], [10]. Negative-parity band structures having similar characteristics and based on a $\nu \mathrm{h}_{11/2}$ quasineutron configuration have been reported by all works. The situation is significantly more complex for the low-spin positive-parity states. A comparison of the band structures developed in ^{119}Xe with those recently established in the neighbouring isotope ^{121}Xe [11], [12] shows clearly a similar behaviour for the $\Delta = 1$ bands built on the $\nu \mathrm{d}_{5/2}[402]5/2^{+}$ ground-state of the two nuclei.

Additional experiments are needed to firmly establish the spin, parity assignments and deexcitation modes of the other low-lying states. Comparing the ^{121}Xe low-lying positive-parity states fed in the ^{121m,g}Cs beta-decays [4] and those with spin-parity $\mathrm{I}^{\pi} \leq 11/2^{+}$ populated in the $^{109}\mathrm{Ag}(^{16}\mathrm{O}, \mathrm{p3n})$ reaction (bands $9 - 10$ and $11 - 12$ in [12]) one observes an interesting agreement. Keeping this similarities in mind, a special effort has been made in the present ^{119m,g}Cs beta-decay study to establish the spin and parity assignments of the low-lying states fed in ^{119}Xe and to combine them with those proposed from recent in-beam $\gamma-$ray spectroscopy studies [9], [10].

In section 2 of this paper the experimental procedures and the results are reported. The level scheme is established in section 3 and the $\beta-$feedings in section 4. The discussion of the new results is presented in the last part, including comparisons with other experimental data and with calculations performed in the frame of the interacting boson-fermion model (IBFM).

2 EXPERIMENTAL PROCEDURES AND RESULTS

The present study of the β/EC decay of ^{119m,g}Cs to levels in ^{119}Xe was completed in part at the ISOLDE facility at CERN and at the UNISOR isotope separator at Oak Ridge National Laboratory (ORNL).

In the studies at ISOLDE, cesium isotopes were produced in a thick molten lanthanum target bombarbed by the 600 MeV proton beam available at CERN. The experimental set-up was similar to the one described in a previous paper on the ^{121m,g}Cs decay [4]. Separated radioactive samples were collected during various collecting times in the 1 to 30 seconds range, and sequentially transported to the counting station by an automatic tape driver system. The counting times were typically of 30 seconds. Singles $\gamma-$ray spectra and time-dependent multiscaling spectra were recorded with an intrinsic Ge detector having a resolution of 800 eV at 122 keV for the low-energy $\gamma-$rays and with several other Ge(Li) coaxial detectors (15% efficiency and $R \approx 2.5$ keV at 1 MeV).

Conversion electron spectra were detected with a movable 3 mm thick Si(Li) detector having a resolution of 1.6 keV FWHM at 624 keV and placed in the vacuum,near the collected samples. Three parameter $\gamma-\gamma-$t and $\gamma-$e $-$ t coincidence events have been recorded. For $\beta^{+}-\gamma$ coincidence measurements, a typical arrangement including a $4\pi\beta$

plastic scintillator and a Ge(Li) detector has been used. This disposal is of the same type as the one used at the TRISTAN mass separator [13].

In the studies at UNISOR, samples of ^{119}Cs were produced in the heavy-ion reaction between a 6 mg/cm^2 ^{92}Mo target, which made the window of the FEBIAD-B2 ion source [14], and a 175 MeV ^{32}S beam provided by the 25 MV Tandem accelerator at the Holifield Heavy Ion Research Facility at ORNL. The evaporation products from the heavy-ion reaction recoiled in the center of the ion source, where they were ionized to a singly-positive charge and extracted towards the mass separator. The recoil ions were then mass separated, and the ^{119}Cs products were deposited into a moving tape, which transported the activity to two counting stations with a cycle time of 40 seconds. The first counting station (G1) consisted of two $\gamma-$ray detectors : a Ge detector with a full energy range set to 1.8 MeV at a distance of 4.4 cm from the source and a Ge(Li) detector, which was placed 4.7 cm from the source position and had a full energy range of 4.0 MeV. A Si(Li) electron detector was also placed at the first detection station (G1) at a distance of 12 cm from the source. The e$^-$ detector was equipped with a mini-orange filter, which was placed between the source and the detector, leaving a distance of 4.5 cm between the detector and the filter. This placement of the mini-orange filter allowed for a peak in the efficiency curve for the electron detector at an energy of 750 keV.

The positions of these three detectors at the first counting station (G1) were such that the two $\gamma-$ray detectors were at 90°, and the electron detector was at 180° relative to one of the Ge detector.

A Ge detector and a Si(Li) electron detector were placed at the second counting station (G3). The Ge detector was placed 4.6 cm from the source position and had a full energy acceptance of 6.0 MeV. The electron detector was placed at 180° to the Ge detector at a distance of 7.0 cm from the source position.

This e$^-$ detector was also served by a mini-orange filter, which was placed 1.5 cm from the face of the detector and resulted in a peak efficiency curve for this detector at an energy of 250 keV.

Singles spectra were collected for each of the five detectors described above. Two-fold coincidences were collected between the two $\gamma-$ray detectors and the electron and Ge detectors at the first counting station (G1), and between the electron and Ge detectors at the second counting station (G3).

Examples of low-energy $\gamma-$ray and conversion electron spectra recorded at ISOLDE are shown in Figs. 1 and 2. Energies and intensities of the $\gamma-$rays associated to the ^{119}Cs decay are listed in Table 2. For both experiments at ISOLDE and at UNISOR the $\gamma-$ray intensities were determined relative to the 176.5 keV gamma-ray transition.

Efficiency curves were derived for each $\gamma-$ray detector using a standard reference source containing ^{154,155}Eu, ^{125}Sb and ^{125m}Te. Energy calibrations were performed by collecting $\gamma-$ray singles spectra for sources of ^{152}Eu and ^{228}Th with the simultaneous collection of the ^{119}Cs activities.

The experimental internal conversion coefficients are listed independently for the two series of measurements. Table 2 concerns low-energy $\gamma-$rays and a few intense transitions at intermediate energy studied at ISOLDE. The coefficients were estimated from singles spectra and normalized to the 176.5 keV, E1 transition, in agreement with its K/L experimental ratio. Table 3 concerns very low-energy transitions for which only L conversion lines were observed. The conversion coefficients measured at UNISOR for the more intense transitions in the decay of ^{119}Cs are listed in Table 4.

Table 3: Same as for Table 2 but for experimental and theoretical α_L internal conversion coefficients.

E_γ (keV)	α_L				Multipolarity
	exp	E1	E2	M1	
67.5	5 (2)	0.075	2.92	0.29	E2
68.0	0.9 (4)	0.073	2.78	0.29	M1
70.3	0.4 (1)	0.066	2.38	0.26	M1

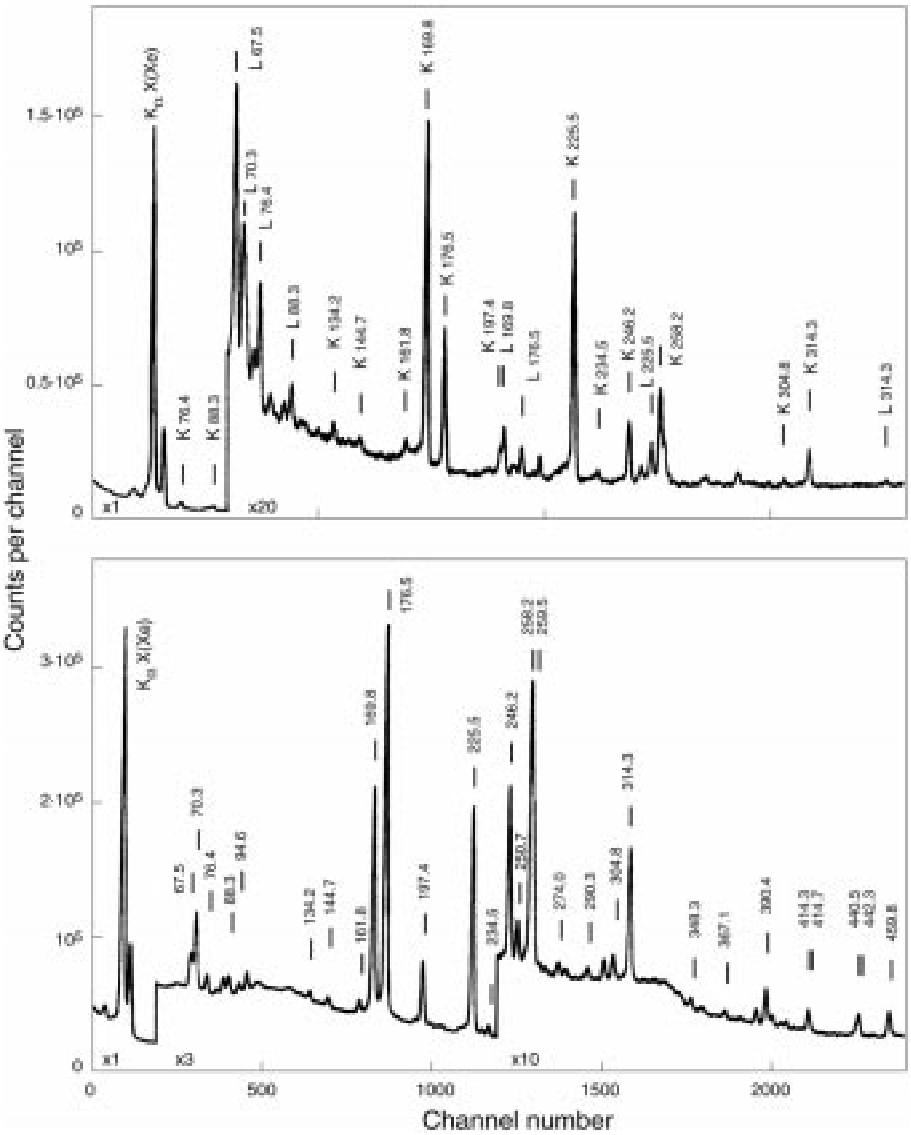

Figure 1: Partial conversion electron (upper panel) and gamma-ray (lower panel) spectra observed in the ^{119m,g}Cs decay at ISOLDE (collecting time 30 s, counting time 30 s).

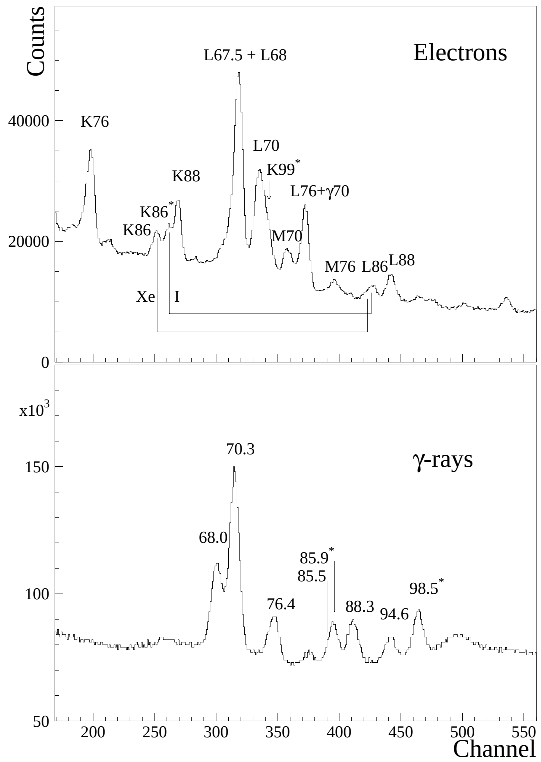

Figure 2: Expanded partial low-energy spectra for $\gamma-$rays (lower panel) and electrons (upper panel), recorded at ISOLDE in the ^{119m,g}Cs decay. They show the complexity of the spectra in the 50 to 100 keV energy range as well as the differences in transition multipolarities. Lines belonging to the decay of ^{119}Xe are labelled with *. Collecting time 1 s, counting time 30 s.

The electron intensities, for each transition, were determined using relative efficiency curves constructed using sources of ^{207}Bi and ^{133}Ba. The curves were normalized by considering the 176.5 keV, which has an E1 multipolarity. As mentioned above,the effect of the mini-orange filter was to peak the efficiency curve towards a specific electron window; the efficiency was peaked at 750 and 250 keV for the electrons in the first and the second stations, respectively.

While the existence of two long-lived species in ^{119}Cs was established and confirmed by many experiments, half-life evaluations are still scattered. The assignment of the $I^\pi = 9/2^+$ state to the ground-state was based on systematics of spins and magnetic moments in the odd-A cesium isotopes [3], [5].

For this state, a half-life $T_{1/2} = 43.0 \pm 0.2$ s is given in the Nuclear Data Sheets [15], in agreement with unpublished results [16]. Since the first evaluation $T_{1/2} = (33 \pm 8)$ s [17], other values have been successively reported: (37.7 ± 0.2) s [18], (44 ± 2) s [3], 36 s [5], (44 ± 3) s [6]. The situation is somewhat similar for the isomeric $I^\pi = 3/2^+$ state. A very precise half-life $T_{1/2} = (30.4 \pm 0.1)$ s is reported in the last compilations [15] while all the other experimental values appear somewhat smaller: 28 s [19], [5], (29 ± 2) s [3], [6].

The time spectra established in the present study for a large number of $\gamma-$rays belonging to ^{119}Xe give a set of half-life values from 29 s to 43 s, as shown in Fig. 3. After having established the ^{119}Xe level scheme fed simultaneously from the two long-lived ^{119m}Cs and ^{119g}Cs states (see section 3) this special situation is clearly understood. Indeed, as it will be presented later, a few high-spin ($I \geq 7/2$) excited levels in ^{119}Xe are populated by the $I^\pi = 9/2^+$ ^{119g}Cs (see part (a) of Fig. 3) while the levels characterized by spin value I = 1/2, 3/2 or 5/2 are essentially fed by the $I^\pi = 3/2^+$ ^{119m}Cs isomer (see part (b) of Fig. 3). Obviously, in between these two extreme situations, as excited states which are not directly fed (or partially fed) by beta decay exist, many $\gamma-$rays in ^{119}Xe will exhibit intermediate half-lives. Two examples are shown in part (c) of Fig. 3 for the intense $\gamma-$rays at 169.8 keV and 197.4 keV which decay with a $T_{1/2} = (38 \pm 1)$ s half-life. Taking into account the collecting and counting times used in the present work and the complexity of the ^{119}Xe level scheme (discussed later in section 3) we estimate that it is very difficult to reach very precise half-life values. The following half-lives can be retained: $T_{1/2} = (43 \pm 1)$ s for the $I^\pi = 9/2^+$ ^{119g}Cs ground-state and $T_{1/2} = (29 \pm 1)$ s for the $I^\pi = 3/2^+$ ^{119m}Cs isomeric state. These results are in good agreement with those reported in the Nuclear Data Sheets compilations [15], except for the error estimations.

Finally the situation in ^{119}Cs is definitively very similar to the one already studied in ^{121}Cs [4]. The identification of two long-lived states I = 9/2 and I = 3/2 in both nuclei has been firmly established from on-line atomic beam magnetic resonance (ABMR) [19], [20] and by $\beta-$radiation detected optical pumping ($\beta-$RADOP) [21] experiments at ISOLDE. In both nuclei, the observation, by in-beam gamma spectroscopy [22] of $\Delta I = 1$ band structures built on the $9/2^+$ states associates a $9/2^+[404]$ $\pi g9/2$ Nilsson configuration for these states.

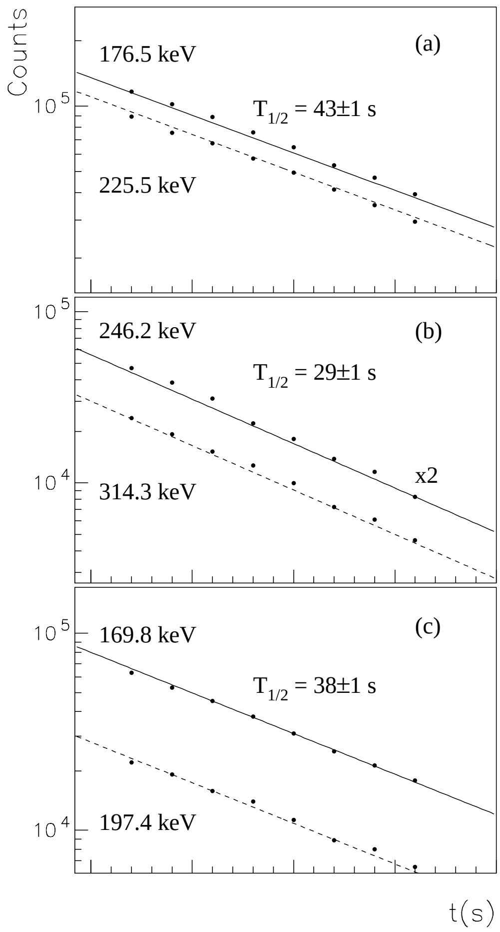

Figure 3: Examples of time spectra measured for several ^{119}Xe γ lines in the ^{119m,g}Cs decays. (a) : ^{119g}Cs decay, (b) : ^{119m}Cs decay, (c) : lines having a complex feeding.

From K and L conversion electron measurements, a direct 68.5 keV, $9/2^+ \rightarrow 3/2^+$ isomeric transition, with a M3 multipolarity has been identified in ^{121}Cs [4]. Obviously, a highly converted isomeric transition could appear in ^{119}Cs. However, no lines in coincidence with the K_α Cs X-rays, no conversion-electron lines from about 8 keV (energy limit in the spectra) to 50 keV and no very low-energy $\gamma-$rays were observed. In conclusion, if a highly converted M3 transition exists in ^{119}Cs with a branching of a few %, its energy would very likely be less than $10 - 15$ keV.

3 THE ^{119}Xe LEVEL SHEME

The ^{119}Xe level scheme obtained in the present work is shown in Figs. 4 (Part I), 5 (Part II) and 6 (Part III). It is based upon a $I^\pi = 5/2^+$ ground-state, previously identified as a $5/2^+[402]$ Nilsson neutron configuration [5]. The strongest $\gamma-$rays populated in ^{119}Xe have been used to establish the lowest excited states. The placement of the transitions has been determined by their coincidence relationships, their intensities (Table 1) and multipolarities (Table 2, 3 and 4). The (β + EC) feedings have also added arguments for spin and parity assignments of several levels in ^{119}Xe (see Table 5 and next section). Figure 7, which contains only part of the ^{119}Xe level scheme extracted from our works, will be used in the following, instead of Figs. 4, 5 and 6, to discuss the results and assign the first members of several band structures, some of them being well observed and extended by in-beam spectroscopy studies.

The negative-parity group of levels, $7/2^-$, $11/2^-$, $9/2^-$, $13/2^-$, displayed at the right hand side of Fig. 7, is strongly fed from ^{119g}Cs. It deexcites to the $5/2^+$ ground-state via the strongest 176.5 keV, $7/2^- \rightarrow 5/2^+$, $\gamma-$ray which has an E1 multipolarity and is fed by the $T_{1/2}$ = 43 s long half-life component of the ^{119}Cs $\beta-$decay (Fig. 3). These levels are similar to those previously identified as the $\nu h_{11/2}$ yrast band from in-beam measurements [7], [8], [9], [10]. In the present $\beta-$decay study a $\gamma-$ray at 68 keV was observed as a doublet which exhibits an intermediate half-life $T_{1/2}$ = 39 s. However, from L-conversion electron spectra, it is possible to confirm the E2 multipolarity of a $11/2^- \rightarrow 7/2^-$, 67.5 keV transition (see Table 3) previously proposed in the first in-beam studies [7], [8].