Eur. Phys. J. A **26**, 233–239 (2005)
DOI 10.1140/epja/i2005-10171-6

THE EUROPEAN PHYSICAL JOURNAL A

Energy systematics of low-lying Nilsson levels in odd-mass einsteinium isotopes

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Received: 1 August 2005 /
Published online: 8 December 2005 –
Communicated by D. Schwalm

Abstract. The decay of odd-mass mendelevium isotopes ($A = 247$–255) has been studied by means of α-γ spectroscopy. Strong evidence for a small α branch in the decay of ^{253}Md was found. γ lines in coincidence with α-decays of ^{247,249,251,253}Md have been observed for the first time. Levels in the einsteinium daughter nuclei were assigned on the basis of α-γ coincidence measurements. An energy systematics of the $7/2^-$[514] Nilsson level could be established, showing a correlation with the deformation parameter β_2 of the corresponding nuclei. The results are compared with theoretical predictions

PACS. 23.60.+e α decay – 27.90.+b $220 \leq A$

1 Introduction

Low-lying nuclear levels in odd-mass transuranium isotopes are essentially determined by the unpaired nucleon. In even-Z nuclei similarities in the α-decay pattern as well as for excitation energies and ordering of low-lying Nilsson levels are well known for isotones. Vice versa such similarities are expected for odd-Z nuclei along the isotope lines. Indeed such trends have been established up to $Z = 97$ (berkelium) (see, *e.g.*, [1,2] and references therein). For the next heavier element (einsteinium, $Z = 99$) data on nuclear levels were scarce so far. Some detailed information on excited levels were only available for ^{251}Es, from EC decay of ^{251}Fm [3] and α-decay of ^{255}Md [4], and for ^{253}Es [5], essentially from α-decay of ^{257}Md. In order to obtain first information on nuclear levels in lighter einsteinium isotopes we performed a series of experiments to study the α-decay of mendelevium isotopes including α-γ coincidence measurements. In this paper an overview of the results concerning the latter technique will be given.

2 Experiment

The experiments were performed at GSI, Darmstadt. Beams of ^{48}Ca were delivered by the high charge state injector with ECR ion source of the UNILAC accelerator, while the ^{40}Ar and ^{50}Ti beams were delivered from the PIG ion source. Beam parameters and reactions used to produce the investigated nuclides are given in table 1. The targets were prepared from isotopically enriched material of ^{208}Pb (enrichment 98.6%), ^{207}Pb (92.4% and 98.9%), and chemically purified ^{209}Bi. Layers of 400–450 μg/cm^2 thickness were evaporated on carbon foils of 40 μg/cm^2 (positioned upstream), which were covered by evaporation of 5–20 μg/cm^2 carbon. The target layer consisted of metallic lead or bismuth. In part of the irradiations, PbS or Bi_2O_3 compounds were used [6], because these materials better withstood highest beam currents due to their higher melting points. The targets were mounted on a wheel which rotated synchronously to the beam macro structure (5 ms wide pulses at 50 Hz repetition frequency) [7].

The evaporation residues leaving the targets with energies $\approx$ 40–50 MeV (^{48}Ca-, ^{50}Ti-induced reactions) or $\approx$ 30 MeV (^{40}Ar-induced reaction) were separated from the primary beam by the velocity filter SHIP [8]. In the focal plane they were implanted into a position-sensitive 16-strip PIPS detector ("stop detector") with an active area of $80 \times 35\,\mathrm{mm}^2$ for measuring the kinetic energies of the residues as well as the subsequent α-decays [9,10]. Gamma rays emitted in prompt or delayed coincidence

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Table 1. Summary of beam parameters and reactions used for the production of ^{247,249,251,253,255}Md.

Projectile	Target	Evap. residue	E_{proj}/A MeV	$I/$ pμA$^{(a)}$	$\epsilon_{SHIP}{}^{(b)}$	σ/nb$^{(c)}$
^{40}Ar	^{209}Bi	^{247}Md	4.95	2.2	0.3	6.9
^{50}Ti	^{209}Bi	^{257}Db ($\xrightarrow{\alpha}$ ^{253}Lr $\xrightarrow{\alpha}$ ^{249}Md)	4.85	0.35	0.4	2.5
^{48}Ca	^{209}Bi	^{253}Lr ($\xrightarrow{\alpha}$ ^{249}Md)	5.05	0.8	0.4	1
^{48}Ca	^{209}Bi	^{255}Lr ($\xrightarrow{\alpha}$ ^{251}Md)	4.55–4.65	1.1	0.4	170
^{48}Ca	^{207}Pb	^{253}No ($\xrightarrow{EC}$ ^{253}Md)	4.6	0.8	0.4	700
^{48}Ca	^{209}Bi	^{255}Lr ($\xrightarrow{EC}$ ^{255}No $\xrightarrow{EC}$ ^{255}Md)	4.55–4.65	1.1	0.4	200
^{48}Ca	^{208}Pb	^{255}No ($\xrightarrow{EC}$ ^{255}Md)	4.45	1.1	0.4	180

(^{a}) Average beam intensity.
(^{b}) Calculated value.
(^{c}) The maximum value for the evaporation residue was used in the case of several bombarding energies.

with α-decays were measured using a clover detector consisting of four Ge crystals (70 mm ⌀, 140 mm length), which were shaped and assembled to form a block of $124 \times 124 \times 140\,\text{mm}^3$. This arrangement is used as standard detector system in experiments to investigate heaviest nuclei. Details, also concerning calibration procedures and efficiency estimations can be found elsewhere [11,12].

The hindrance factor (HF) for an α transition is defined as the ratio $T_{\alpha,exp}$ / $T_{\alpha,theo}$ with $T_{\alpha,exp} = T_{1/2}/(b_\alpha \times i_\alpha)$, where $T_{1/2}$ and b_α denote the half-life and the α branching of the parent state and i_α is the intensity of the transition relative to all α transitions. The theoretical half-life was calculated using the formula proposed by Poenaru *et al.* [13] with the parameter modification suggested by Rurarz [14]. Hindrance factors are usually divided into four categories characterizing similarities and differences in the structure of parent and daughter states (see, *e.g.*, [15] and references therein). Alpha transitions in odd-mass nuclei where the unpaired nucleon remains in the same orbital in the parent and daughter nucleus are characterized by low hindrance factors of 1–4 (favoured transitions).

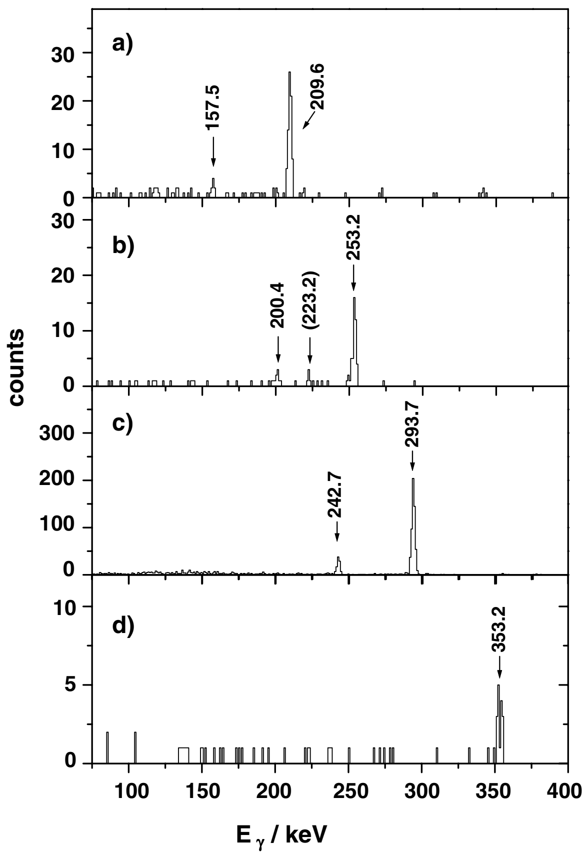

Fig. 1. Gamma spectra observed in prompt coincidence with α-decays of (a) ^{247}Md, (b) ^{249}Md, (c) ^{251}Md, (d) ^{253}Md (tentative assignment).

3 Experimental results

3.1 Decay of ^{247}Md

^{247}Md was produced via the reaction ^{209}Bi(^{40}Ar, 2n) ^{247}Md. In a first experiment aimed on α-γ coincidence measurements a γ line of 210 keV was observed in coincidence with the known α transition of 8425 keV [16]. From the intensity ratio of K X-rays and γ-rays it was concluded that the multipolarity of the transition was most probably $E1$. To improve the quality of the data and to affirm the results, a second experiment was performed. Results of this study are reported in detail elsewhere [17]. The α-γ coincidence data are presented in fig. 1a and table 2. In addition to the known 209.6 keV γ line a weaker one of 157.5 keV

Table 2. Results of the α-γ decay studies.

Isotope	E_α/keV	E_γ/keV	$i_{rel,\gamma}$	α_K (exp)	α_L (exp)	α_K (theo) ($E1, E2, M1$)	α_L (theo) ($E1, E2, M1$)	Multipol.
^{247}Md	8422 ± 10	209.6 ± 0.3 157.5 ± 0.5	1 0.11 ± 0.03	≤ 0.13	≤ 0.04	0.08, 0.13, 4.3	0.02, 0.86, 1.03	$E1$
^{249}Md	8026 ± 10	253.2 ± 0.3 200.4 ± 0.7 223.2 ± 0.5	1 0.2 ± 0.08 0.1 ± 0.05	≤ 0.09	≤ 0.034	0.05, 0.11, 2.5	0.012, 0.31, 0.55	$E1$
^{251}Md	7540 ± 10	293.7 ± 0.1 242.7 ± 0.3	1 0.16 ± 0.02	≤ 0.08	≤ 0.16	0.04, 0.09, 1.6	0.008, 0.17, 0.37	$E1$
^{253}Md	7100 ± 15	353.2 ± 0.4	1	≤ 0.06		0.04, 0.09, 1.6		($E1$)
^{255}Md	7313 ± 15	452.8 ± 0.3 405.2 ± 0.3	1 0.76 ± 0.08					($E1$)

was observed. The energy distribution of the α-particles in coincidence with this line was broader than for those in coincidence with the 209.6 keV line and the "peak" was shifted by ≈ 40 keV, so evidently it was affected by energy summing with conversion electrons [18]. Therefore, this line was interpreted as due to be emitted from the same nuclear level as the 209.6 keV line, but populating a state decaying predominantly by internal conversion.

Since K-fluorescence yields are close to unity in heaviest nuclei, K conversion coefficients can principally be derived from the ratio of K X-rays and γ-rays. Strictly, this is true if only one transition is involved. If several final states are populated by decay of one initial state, X-rays connected to the different transitions can be hardly distinguished. If, on the other hand, several initial states decay into a certain final state, due to energy summing between α-particles and conversion electrons, the summed signal coincident with the X-rays will be similar and thus also the intensities of X-rays from different transitions can be hardly determined. Therefore, the ratio between X-rays and γ-rays in general can only be regarded as an upper limit for the K conversion coefficient. Our value for the 209.6 keV transition is given in table 2. Since the clover detector is not sufficiently sensitive to L X-rays, estimates on L conversion coefficients can be obtained only roughly analyzing energy summing between α-particles and L conversion electrons. If lower-lying levels are not populated significantly by α-decay, the ratio of α-particles in the energy range of those coincident with the γ line with those in the expected range of conversion electron - α sum events can be regarded as a rough measure of the L conversion coefficient (see [11] for further details). Our value obtained by this method for the 209.6 keV transition is given in table 2. In addition to these unambiguously identified transitions, evidence for weaker lines was found, which could be a hint that the 209.6 keV γ line does not represent the transition into the ground state. The data are so far not fully conclusive and need to be affirmed.

3.2 Decay of ^{249}Md

The isotope was produced in two reactions, ^{209}Bi(^{50}Ti, 2n)^{257m,257g}Db $\xrightarrow{\alpha}$ ^{253m,253g}Lr $\xrightarrow{\alpha}$ ^{249}Md and ^{209}Bi(^{48}Ca, 4n)^{253m,253g}Lr $\xrightarrow{\alpha}$ ^{249}Md. In coincidence with α-decays of ^{249}Md, three γ lines of 253.2 keV, 223.2 keV and 200.4 keV were observed. The results are presented in fig. 1b and table 2. It was already found earlier, that ^{257m}Db decays exclusively into ^{253m}Lr, while ^{257g}Db decays exclusively into ^{253g}Lr [19]. In this paper also the possible existence of an isomeric state in ^{249}Md decaying by α emission was discussed, but the data did not allow for definite conclusions. Our experiments showed that the γ lines were observed in coincidence with ^{249}Md α-decays following those of ^{253m}Lr as well as with those following decays of ^{253g}Lr. So, if an isomeric state ^{249m}Md is populated by α-decay of ^{253m}Lr it can be assumed that its α-decay branch is small compared to its branch for the decay via internal transitions into the ground state.

3.3 Decay of ^{251}Md

The isotope was produced by the reactions ^{209}Bi(^{48}Ca, 2n)^{255m,255g}Lr $\xrightarrow{\alpha}$ ^{251}Md. In our first experiment we observed a γ line of 295 keV in coincidence with α-particles of ^{251}Md [20], which was later principally confirmed by Chatillon *et al.* [21,22], who, in addition, observed a second γ line of 243.2 keV. To confirm the latter result and also to search for further γ lines in coincidence with

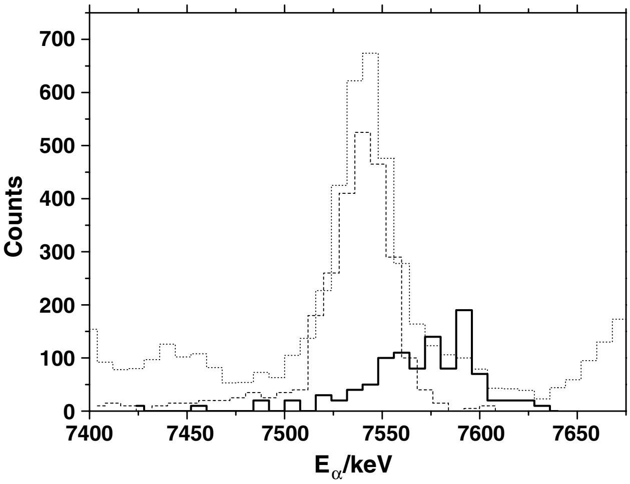

Fig. 2. Comparison of α-decays of ^{251}Md without γ coincidence condition (dotted line), coincident with 293.7 keV (dashed line), coincident with 242.7 keV (full line). Intensities are scaled by factors of four (coincidences with 293.7 keV) or ten (coincidences with 242.7 keV) for better presentation.

α-decays of ^{251}Md we repeated the experiment with higher precision. The results are shown in fig. 1c and listed in table 2. Our previous γ line could be reproduced within the calibration accuracy, our improved value is 293.7 keV, and we also observed a second γ line at 242.7 keV. In addition to the dominant α transition of 7550 keV Chatillon *et al.* [21,22] report a weaker α line of 7590 keV not in coincidence with their 243.2 keV γ events. This line was not clearly present in our data (see fig. 2). We just observed a shoulder at the 7540 keV line towards higher energies (dotted line in fig. 2), which was not present in the "narrow" energy distribution of α-particles coincident with the 293.7 keV line (dashed line in fig. 2). The energy distribution of the α-particles coincident with our 242.7 keV line, however, was found to be broad and its high-energy part covers the energy range of the "shoulder". Such a distribution is typical for energy summing between α-particles and conversion electrons [11]. Therefore, we interpret the two γ lines as due to the decay of the same initial state (populated by the α-decay) into different final states.

Similar to the cases discussed above we estimated upper limits (given in table 2) for the K and L conversion coefficients for the 293.7 keV transition.

No other γ line was observed clearly in coincidence with α-decays of ^{251}Md. Thus, an upper intensity (i) limit for other γ transitions in coincidence with α-decays of ^{251}Md of $i/i(293.7\ \text{keV}) \leq 0.05$ can be given.

3.4 Decay of ^{253}Md

A so far unknown α-γ coincidence of $E_\alpha = 7100 \pm 15$ keV, $E_\gamma = 353.2 \pm 0.4$ keV (fig. 1d) was observed in irradiations of ^{207}Pb with ^{48}Ca at beam energies $E = 4.58, 4.60$ A MeV, aimed at investigating the decay of ^{253}No. This activity, however, was not observed in irradiations of ^{206,208}Pb or ^{209}Bi with ^{48}Ca at similar bombarding energies, where ^{253}No was not (or only with little intensity) observed. Thus, the occurrence of this activity seemingly was connected to the production of ^{253}No and it seemed straightforward to assign it to a decay product of this isotope. The α-γ energy combination, however, did not fit to any known decay product of which an α-decay branch had been reported so far. Thus, a possible candidate is a so far unknown α-decay branch in ^{253}Md. Such an assignment is further based on two arguments: a) for ^{253}No an EC branch of $\approx 30\%$ is reported [23]. Therefore, from the observed numbers of ^{253}No α-decays, the numbers of α-γ coincidences and a clover efficiency of $\approx 10\%$ at 353 keV [12], an "experimental" α branch of $\approx 0.7\%$ can be estimated for ^{253}Md. Using the formalism of [13] to calculate the partial α half-life for $E_\alpha = 7.1$ MeV and an experimental half-life of ≈ 240 s, one obtains an expected α branch of $\approx 0.3\%$, which is similar to the "experimental" one. b) The α-decay Q value, approximately represented by the sum $Q_\alpha + E_\gamma = 7.57$ MeV, exhibits a local minimum within the series of odd-mass Md isotopes, as expected for the isotope at the $N = 152$ neutron shell.

However, one peculiarity should be mentioned: only one γ line was observed in coincidence with α-decays, while for the other isotopes two lines having an energy difference of ≈ 50 keV were safely identified. Their intensity ratios are seemingly correlated to the γ energies exhibiting a trend of decreasing relative intensities of the lower energetic lines with decreasing γ energy (see table 2). So, naively, one expects for the ^{253}Md decay an intensity of a second γ line in-between the values for ^{251}Md ($\approx 16\%$) and ^{255}Md ($\approx 73\%$) or, on the basis of fifteen observed α-γ coincidences for $E_\gamma = 353$ keV, 3–11 γ events around 300 keV. However, no event was observed. Therefore, we regard our assignment presently as tentative.

3.5 Decay of ^{255}Md

A detailed α-γ decay study of this isotope was performed by Ahmad *et al.* [4], who observed two γ lines of 453.0 ± 0.3 keV ($i_{rel} = 1$) and 405.5 ± 0.3 keV ($i_{rel} = 0.73$) in coincidence with the strongest α line of 7327 ± 4 keV. The γ lines were attributed to the transitions $7/2^-[514] \rightarrow 7/2^+[633]$ and $7/2^-[514] \rightarrow 9/2^+$ in the daughter nucleus ^{251}Es. In our experiments ^{255}Md was produced via the EC decay chain $^{255}\text{Lr} \overset{\text{EC}}{\rightarrow} {}^{255}\text{No} \overset{\text{EC}}{\rightarrow} {}^{255}\text{Md}$. Altogether about 200 γ events were observed in coincidence with α-decays of ^{255}Md. We regard our results just as a confirmation of the data of Ahmad *et al.* and list them for completeness in table 2.

4 Discussion

Partial decay schemes of ^{247,249,251,253,255}Md as obtained from our experiments are shown in fig. 3, while a comparison of low-lying levels in the einsteinium daughter isotopes including also the results from [4] for ^{251}Es and [5] for ^{253}Es with theoretical predictions [24,25] is presented

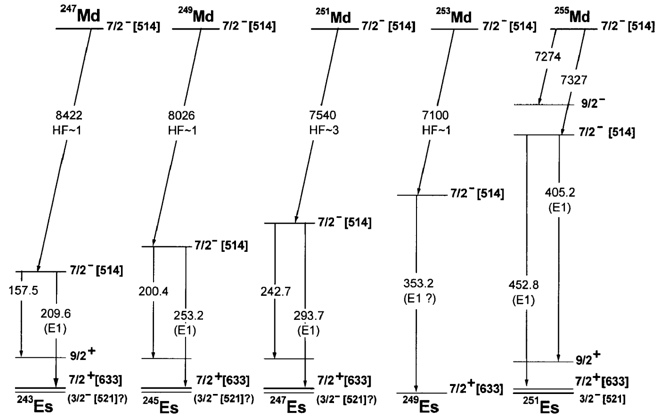

Fig. 3. Decay schemes of odd-mass medelevium isotopes according to the results of the present experiments. For ^{255}Md also the results from [4] are included.

in fig. 4. A regular trend of increasing γ energies with increasing mass number is evident in fig. 3. The 209.6 keV and 253.2 keV transitions in ^{247}Md and ^{249}Md, respectively, are assigned as $E1$ according to the upper limit of the L conversion coefficient (table 2). For ^{251}Md the situation is not so clear. The method of determining the (upper limit of the) L conversion coefficient described above delivers here a quite high value due to the background from α-decay of ^{255}No (produced by EC decay of ^{255}Lr) in the energy region of the expected α - conversion electron sum events from ^{251}Md (7.70–7.85 MeV). Although $E2$ multipolarity cannot be ruled out, according to the upper limits $E1$ seems to be the appropriate choice, which is corroborated by the regular behavior of γ energies and intensities for ^{247,249,251}Md. For ^{253}Md, due to the weakness of the α line, only an upper limit for α_K could be estimated. It is in line with $E1$ and $E2$ multipolarities. Also here we tentatively prefer $E1$ on the basis of the systematic behavior for the mendelevium isotopes. The level assignments are based on the multipolarity of the γ transitions and predicted or experimentally assigned low-lying levels in the mother and daughter nuclei. Possible low-lying levels that have to be respected are $7/2^-[514]$ and $1/2^-[521]$ in the mendelevium isotopes and $3/2^-[521]$ and $7/2^+[633]$ in the einsteinium isotopes. We further use the experimental result that the respective α-decays represent "favored transitions". A scheme of possible electromagnetic transitions is given in table 3. Evidently $E1$ transitions are only in line with the initial-final state combination $7/2^-[514]$-$7/2^+[633]$, which defines the ground states of the mendelevium isotopes as $7/2^-[514]$ and is thus in line with the assignment of the ground state of ^{255}Md [3, 4] and the tentative assignments of the ground states of ^{249}Md [19] and ^{257}Md [26,5].

Ground-state assignments of the einsteinium daughter isotopes are not straightforward. Although the final states are assigned to $7/2^+[633]$, they may not represent the ground states. In ^{253}Es the ground state is assigned to $7/2^+[633]$ [5]. In ^{251}Es the ground state is assigned to $3/2^-[521]$, while the $7/2^+[633]$ level is located at

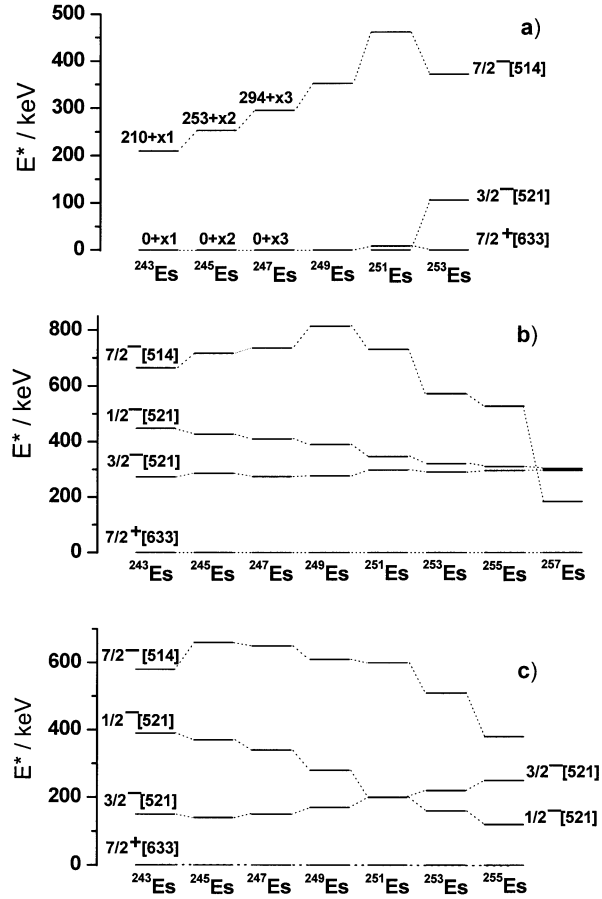

Fig. 4. Comparison of experimental (a) and calculated level schemes from [24] (b) and [25] (c).

Table 3. Scheme of the most probable transition multipolarities for different combinations of spins and parities for the initial and final states.

Initial state	Final state	ΔI	Parity change	Transition mulipolarity
$1/2^-[521]$	$7/2^+[633]$	3	yes	$E3$
$1/2^-[521]$	$3/2^-[521]$	1	no	$M1$
$7/2^-[514]$	$7/2^+[633]$	0	yes	$E1$
$7/2^-[514]$	$3/2^-[521]$	2	no	$E2$

8.3 keV [4]. In ^{249}Es, on the other hand, the ground state was tentatively assigned to $7/2^+[633]$ [27]. Ground-state assignments on the basis of α-decay properties were performed by Hatsukawa *et al.* [28]. They assigned the ground state of ^{247}Es to $7/2^+[633]$, those of ^{245,243}Es to $3/2^-[521]$. However, due to measuring solely α-decay, the results of ref. [28] may not be fully conclusive. Indeed, in the case of ^{243}Es we could not reproduce the 7.939 MeV line on which their level assignment is based [16,17]. An indication that $3/2^-[521]$ may be the ground state rather than $7/2^+[633]$ is obtained in our work from a weak γ transition of 272.3 keV in coincidence with 8377 keV α-decays of ^{247}Md (see fig. 1a). The Q value for this coincidence is roughly

20 keV higher than for the 8422 keV (α) - 209.6 keV (γ) coincidence. The data are, however, presently too scarce to draw conclusions. Consequently, if the ground states are $3/2^-[521]$, also the energies for the $7/2^+[633]$ and $7/2^-[514]$ levels are uncertain. Therefore, we have denoted in fig. 4a the level energies for ^{243,245,247}Es as $(E+xi, i = 1\text{–}3)$. An upper value for xi can be estimated on the basis of systematics for the energy differences between the $5/2^-$ level and the band head $3/2^-[521]$ in odd-Z nuclei [2]. Typically the energy difference between these two states is $\Delta E \approx 30$ keV. If the $7/2^+[633]$ state is located above the $5/2^-$ level, it will decay by an $E1$ transition to this state rather than by an $M2$ transition into the $3/2^-[521]$ state. The $5/2^-$ level then will decay by an $M1$ transition into the $3/2^-[521]$ state. According to Weisskopf estimation, expected lifetimes are lower than 10^{-10} s for $M1$ transitions and higher than 10^{-6} s for $M2$. Thus, for an $M1$ transition, energy summing between α-particles and conversion electrons is expected, while for an $M2$ transition the probability for summing will be low due to the long lifetime. Since our α lines of ^{247,249,251}Md in coincidence with the 209.6, 253.2 und 293.7 keV γ lines do not show evidence for energy summing with conversion electrons, we conclude that the $7/2^+[633]$ level is located below the $5/2^-$ state and thus $E^*(7/2^+[633])$ is lower than 30 keV.

The γ transitions of 157.5 keV (^{243}Es) and 242.7 keV (^{247}Es) are attributed to the decay into the $9/2^+$ member of the rotational band built on the $7/2^+[633]$ Nilsson level due to the characteristics of the coincident α-particles (energy summing with conversion electrons) and energy differences to the more intense lines similar to that of the 452.8 keV and 405.2 keV transitions observed in ^{251}Es (fig. 3). Due to the latter reason, in ^{245}Es the 200.4 keV transition is assigned to the transition into the $9/2^+$ level, while the weaker transition of 223.2 keV presently remains unassigned.

Summarizing the discussion it can be concluded that ground-state assignments of light einsteinium isotopes ($A \leq 249$) are still uncertain. Two low-lying Nilsson levels ($7/2^+[633]$, $3/2^-[521]$) may alternate as ground states.

This behavior is opposite to the theoretical predictions shown in figs. 4b and c. Cwiok *et al.* [24] as well as Parkhomenko *et al.* [25] predict $7/2^+[633]$ as ground states and the $3/2^-[521]$ level at excitation energies of 150–250 keV [25] or 275–295 keV [24], varying only slightly with the mass numbers. From experimental results, an increase of the $7/2^+[633]$ energy with increasing mass numbers up to $A = 251$, where a local maximum occurs, is observed. While the trend of increasing energies (although the maximum is predicted at $A = 249$) is reproduced by Cwiok *et al.*, Parkhomenko predicts decreasing values from $A = 245$ to $A = 255$. The $7/2^-[514]$ level stems from the $1h_{9/2}$ proton configuration and is predicted to increase in energy with increasing ground-state deformation as seen in the Nilsson diagram (see, *e.g.*, [2]), while the $7/2^+[633]$ and the $3/2^-[521]$ levels stem from the $1i_{13/2}$ and $2f_{7/2}$ proton configurations and are predicted to decrease in energy with increasing deformation. In fig. 5 we have plotted the ground-state deformation parameters β_2

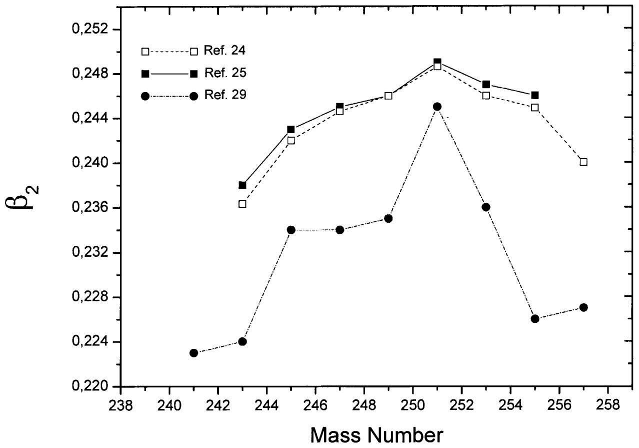

Fig. 5. Calculated ground-state deformation of odd-mass einsteinium isotopes as a function of the mass number according to [25] (full squares), [24] (open squares), [29] (full dots).

as predicted in refs. [24,25,29] as a function of A for odd-mass einsteinium isotopes. All authors predict the maximum deformation at mass number $A = 251$ (*i.e.* at the deformed neutron shell $N = 152$). A direct link between deformation and energy of the $7/2^-[514]$ level cannot be expected *a priori*, since the latter reflects the energy difference to the $3/2^-[521]$ or $7/2^+[633]$ level —depending on which the ground state is— and thus also reflects the slope of the increase or decrease, respectively. Nevertheless, comparing figs. 4a and 5, a correlation between the experimental excitation energy for the $7/2^-[514]$ and the deformation parameter β_2 is observed although the positions of the maxima do not agree exactly.

Besides the levels discussed above, theories [25,24] predict the $1/2^-[521]$ Nilsson level below 500 keV excitation energy in einsteinium isotopes. There is, however, no experimental information on level energies so far. In the odd-mass mendelevium isotopes, the $1/2^-[521]$ level is predicted as the ground state [25,24], contrary to the $7/2^-[514]$ experimental assignments discussed above. Low-lying, possibly isomeric, $1/2^-[521]$ levels in ^{249,251}Md were so far supposed from the decay properties of ^{253m,255m}Lr [19,20], but could not be identified directly. Solely in ^{245,247}Md isomeric states have been identified so far. In ^{245}Md a fission activity of 0.9 ms half-life was assigned to the ground-state decay (tentative level assignment: $1/2^-[521]$), while an α activity of $E_\alpha = 8.64$, 8.68 MeV was attributed to the decay of an isomeric state (tentative level assignment: $7/2^-[514]$ or $7/2^+[633]$) [30]). Probably these tentative assignments have to be revised on the basis of the results presented here. In ^{247}Md a fission activity of 0.23 ms half-life was assigned to an isomeric state, tentatively assigned to $1/2^-[521]$ [31]. In the course of these experiments also α-decay from the isomeric state was observed [20,17]. The low hindrance factor suggests a "favored" transition into the $1/2^-[521]$ Nilsson level in ^{243}Es. There is, however, so far no information on the excitation energy of this level, which may be expected to decay by an $M1$ transition into the $3/2^-[521]$ state.

5 Summary

We have investigated low-lying Nilsson levels in einsteinium isotopes by decay studies of mendelevium isotopes using α-γ coincidence measurements. Our results strongly suggest the $7/2^-[514]$ Nilsson level as ground state in ^{247,249,251,253}Md, which so far was also assigned to ^{255,257}Md. Ground-state assignments of the einsteinium daughter isotopes are still ambiguous on the basis of α-γ coincidence measurements performed so far. The $3/2^-[521]$ and $7/2^+[633]$ are probably close in energy and may alter as the ground state in neighbouring nuclei. The trend in the excitation energy of the $7/2^-[514]$ level was found to be correlated to the ground-state deformation, and the local maximum at $A = 251$ ($N = 152$) was found to coincide with the predicted location of the maximum ground-state deformation. However, more detailed information on the decay is needed. An increase of the counting rates by an order of magnitude is desired and seems possible within the next time. Such rates are necessary to safely identify the low intense transitions indicated in our spectra, which may be the key for an unambiguous assignment of the ground state of the light odd-mass einsteinium isotopes.

We want to express our gratitude to H.G. Burkhard and H.J. Schött for skillful maintenance of the mechanical and electrical components of SHIP. We thank the UNILAC staff as well as K. Tinschert and the "ion source crew" for delivering beams of high and stable intensity and the excellent performance of the accelerator. We are also grateful to J. Steiner, W. Hartmann and A. Hübner for production of the large area targets and preparation of the target wheels.

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