# BETA AND GAMMA RAY STUDIES OF $^{144}$Cs, $^{144}$Ba and $^{144}$La.

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## Abstract

$^{144}$Cs and $^{144}$Ba are easily produced in the isotope separator on line facility (Osiris) in Studsvik. These nuclides were obtained by thermal neutron fission in $^{235}$U, the neutrons coming from the R2-O (Max. 1MW) pool reactor. The recoiling fission fragments are caught by a graphite cloth in the ion source and mass separated. The activity is deposited on a tape transporter and the measurements can be performed either on line or after a transport of the tape. The energies and intensities of the γ lines have been measured in the decay of $^{144}$Cs, $^{144}$Ba and $^{144}$La and the level schemes of $^{144}$Ba and $^{144}$Ce have been established using β-γ and γ-γ coincidence measurements with Ge(Li) detectors. 12 levels have been placed in $^{144}$Ba and 25 in $^{144}$Ce. The half-life of the first excited state at 199 keV in $^{144}$Ba has been measured : $T_{1/2}$= 0.85 ± 0.15 nsec. The results are discussed and compared with other recent studies of the neighbouring even masses, to provide evidence for the onset of substantial deformation in the transition neutron region of N = 88.

## 1. Introduction

The transitional nuclei with neutron numbers greater than N = 82 are of special interest since they occupy that region of the nucleidic chart wherein the onset of permanent prolate deformation occurs. This is particularly true between N = 88 and N = 90 where the transition from the spherical to the aligned coupling scheme appears to occur rather abruptly. In this work, the decay of A = 144 nuclei : Cs, Ba and La has been studied and the results have been included in a systematic for Z = 56 and 58 and for N = 86 and 88. The γ-rays in the three nuclei reported here Ba, La and Ce, have been poorly studied in the past[1], mainly because of the inability to obtain pure samples of reasonable activity for the parent nuclei. Some γ-rays from the decays of the three nuclei have been reported by Wunsch et al.[2]-very incomplete γ-ray lists for the decay of $^{144}$Ba and/or $^{144}$La have been reported by several authors[3-7] - excepted a partial level scheme for $^{144}$Ce given by Aronsson et al.[7] no investigator attempted to construct a decay scheme.

## 2. Experimental techniques

The activities investigated in the present experiment were obtained as mass-separated fission fragments from the Osiris on-line mass-separator[8] in Studsvik. The separated isotopes were collected on an aluminium coated plastic tape which after suitable collection time permitted rapid transportation of the activities to a position 11 cm above the beam where singles measurements of γ-rays and conversion electron spectra with Ge(Li) and Si(Li) detectors were made. For coincidence measurements two Ge(Li) detectors of 35 and 90 cm$^3$ (resolution of 2.3 and 2.7 keV for the 1.33 MeV γ line of $^{60}$Co) were placed opposite each other, each about 15 mm away from the spot where the ion beam was collected on the tape. The tape transport system was then used to carry away "old" activities.

At mass 144, activities of Cs, Ba and La were obtained from the mass-separator. In order to identify γ-lines from the different decays, activities were collected for a few different time intervals and several consecutive γ-ray spectra were recorded. After thus having determined the half-lives of the activities present in the collected sources, single γ-ray spectra were measured in the upper position with the tape transport time interval adjusted to correspond to optinum conditions for the pertinent decay-rate. By simultaneously recording the corresponding conversion electron spectrum, conversion coefficients could be determined. The atomic number was obtained from the energy difference between lines from K and L electron Shells and also from the K-Shell binding energy. Only relatively strong conversion electron lines were observed due to the high background from β-particles. As calibration points for the determination of conversion coefficients lines emitted in the decays of $^{85m}$Kr and $^{135m}$Xe (obtained from the mass-separator) were used.

Energy calibration of γ-ray were performed by recording spectra from the A=144 isobars simultaneously with reference sources. The contamination from neighbouring mass numbers was insignifiant, but weak γ-rays from the decay of Mass 131 and 132 (Sn and Sb) were observed probably as compounds with the carbone of the ion source.

The equipment for on-line nuclear half-life measurements has been described elsewhere[9]. Briefly, β and γ-rays populating a level of interest are detected in a 2.5 x 2.5 cm$^2$ Naton 136 plastic scintillator, and the deexciting γ-transition is selected in a 2.5 x 2.5 cm$^2$ NaI (Tl) detector. Both scintillators are mounted on XP 1020 photomultipliers.

## 3. Experimental results

### 3.1 Gamma-ray and conversion electron measurements

The spectra of the low energy of the

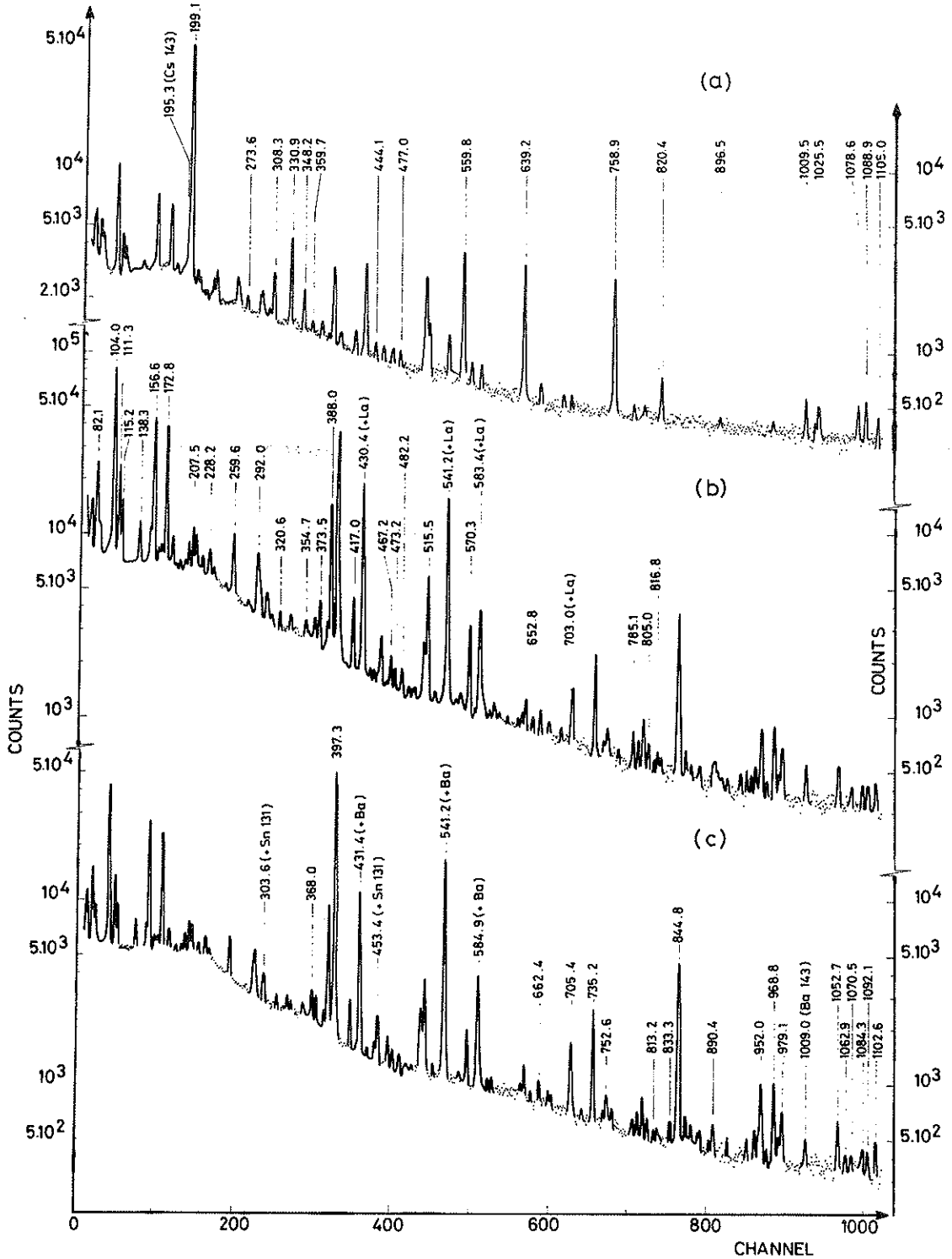


FIG.1 Low energy (60-1150 keV) single spectra for $^{144}$Cs decay enhanced (Curve (a)), $^{144}$Ba decay enhanced (curve (b)) and $^{144}$La decay enhanced (curve (c)).

mass chain A = 144 are shown in fig.1. The fig. 1(a) presents the first of four spectra measured during 0.67 sec each, after an irradiation time of 0.67 x 4 sec. Most of the γ-lines belong to $^{144}$Cs ($T_{1/2}$= 1.06 sec). The γ-ray spectra of the fig.1(b) and 1(c) are the second and the fourth of a series of four spectra measured during 6.7 sec each, after an irradiation time of 6.7 x 4 sec. Most of the γ-lines belong to $^{144}$Ba ($T_{1/2}$ = 13.6 sec) and $^{144}$La ($T_{1/2}$ = 41 sec). 42 γ-rays have been identified in the decay of $^{144}$Cs, but only 25 of them have been placed in a tentative level scheme of $^{144}$Ba (fig.3). Despite of the incompleteness of this level scheme, in which most of the high energy transitions have not been placed, it still accommodates about 83% of the γ-ray intensity assigned to this decay.

The γ-ray spectrum of the decay of $^{144}$Ba is characterized by intense peaks at low energy (fig.1b and 1c). 42 γ-rays have been identified, the highest energy transition seen in the spectrum is at 816.8 keV. The level scheme of $^{144}$La has not been constructed up to now, due to the difficulties of the γ-γ coincidence measurements for the low energy γ-transitions and to the high internal conversion of these transitions.

Among the 64 γ-rays identified in the decay of $^{144}$La 39 transitions (more than 90% of the γ-ray intensity) have been placed in a level scheme of 25 excited states (fig.5).

Informations on the observed conversion electrons lines are given in Table 1. $Q_\beta$-values have been deduced from β-γ coincidence measurements with a plastic scintillator and a Ge(Li) detector. The values obtained are respectively $Q_\beta$=(7.8±0.4) MeV and $Q_\beta$=(5.3±0.3) MeV for the total β-decay of $^{144}$Cs and $^{144}$La.

3.2 Half-life measurement

Fig.2 shows the delayed coincidence curve between γ-transitions feeding and deexciting the 199.1 keV level in $^{144}$Ba. From analysis of the slope of the right hand side of the distribution, a half-live of (0.85 ± 0.15) ns was deduced for this level. This value agrees with previous measurement[11,12,13]. The derived enhancement factor of about 40 for the E2 transition to the ground state is clearly intermediate between the values 15-20 found for spherical nuclei in this mass region and the

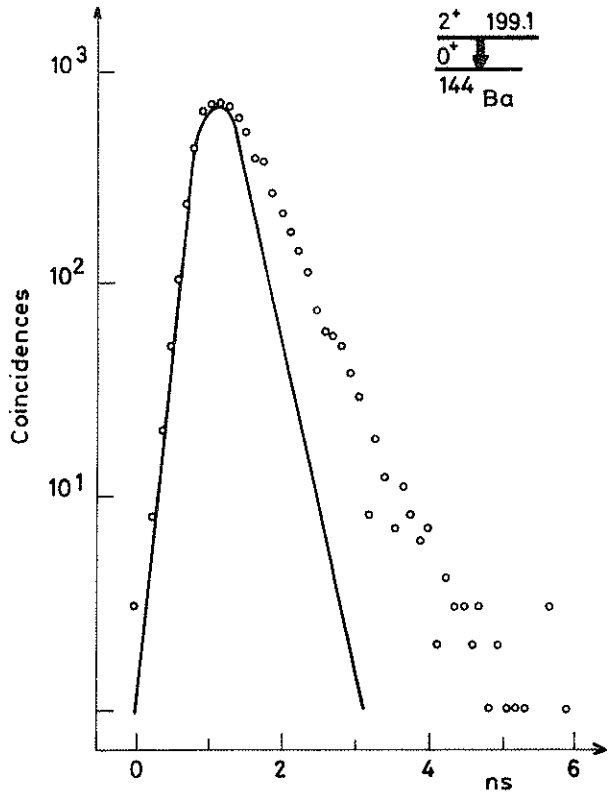


FIG.2 Delayed coïncidence curve between radiation feeding and deexciting the 199.8 keV level in $^{144}$Ba. The solid line shows a prompt comparison time spectrum.

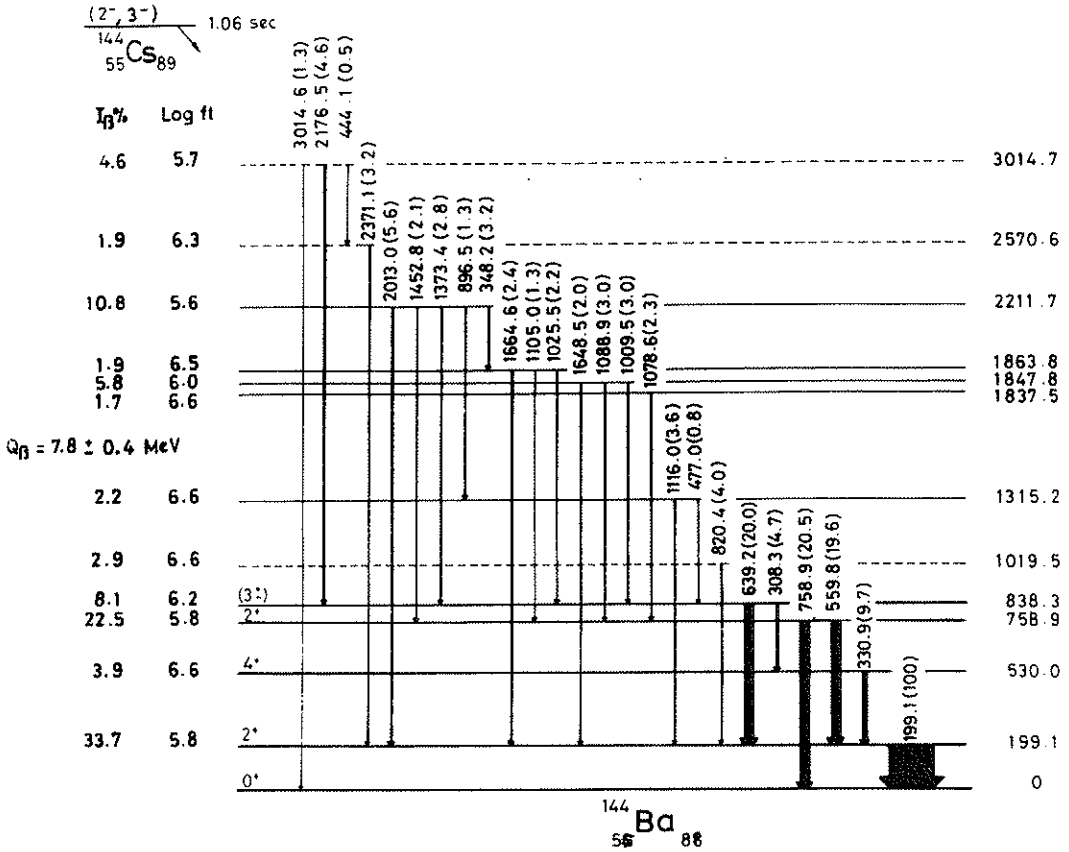


FIG.3 Energy levels and transitions in $^{144}$Ba.Log ft values have been determined from the intensity balance of each level, assuming a negligible β feeding to the ground state and using a total decay energy of 7.8 MeV.

Table 1

Conversion coefficients for some transitions in $^{144}$Ba and $^{144}$Ce

| Transition Energy (keV) | Level Scheme | K-Shell conversion coefficients | | | | Multi-polarity |
|---|---|---|---|---|---|---|
| | | exp.[a] | theory[b] | | | |
| | | | E1 | E2 | M1 | |
| 199.1 | Ba | 0.15 ± 0.02 | 0.029 | 0.13 | 0.12 | E2 |
| 330.9 | Ba | 0.036 ± 0.008 | 0.0078 | 0.028 | 0.033 | E2 or M1 |
| 348.2 | Ba | 0.021 ± 0.012 | 0.0066 | 0.023 | 0.028 | E2 or M1 |
| 397.3 | Ce | 0.019 ± 0.002 | 0.0052 | 0.017 | 0.024 | E2 |
| 541.1 | Ce | 0.0056 ± 0.0020 | 0.0026 | 0.0054 | 0.011 | E2 |

a) The uncertainty from the calibration using conversion electrons from $^{135m}$Xe is included in the errors given for the conversion coefficients.
b) Theoretical values are taken from ref.[10])

values of $\sim 10^2$ which are typical for deformed nuclei.

## 4. Decay scheme

The γ-ray energies and intensities and their coincidence relationships both with internal conversion measurements have been used to construct the proposed decay schemes (fig.3 and 5). Intensities and log ft values for most of the β branches have been estimated using γ intensity-balances and assuming a negligible β feeding to the ground state. This assumption is supported by the β feeding of high spins in $^{144}$Ba and $^{144}$Ce (see sections 4.1 and 4.2), and by a filiation measurement in this mass chain.

### 4.1 Decay scheme of $^{144}$Cs

The γ and e$^-$ measurements of the 199.1 and 330.9 keV transitions show that the levels at 199.1 and 530.0 keV have as characteristics $J^\pi = 2^+$ and $4^+$. These assignments agree with previous results found by Cheifetz et al.[14]) in their study of transition intensities for members of the ground state bands in even-even prompt fission products from $^{252}$Cf.

The level at 758.9 keV is probably the second $2^+$ excited state, since strong γ-rays are observed to feed both the ground state and the first excited state. These two transitions have the same intensity. We can find similar deexitation of the second $2^+$ level in $^{142}$Ba (ref.[15])).

The level at 838.3 keV which is deexcited by two γ-rays feeding both the first $2^+$ and $4^+$ excited states has probably the spin 3 with negative or positive parity. A level $3^-$ may be consistent with the systematic of the nuclei with Z = 56 and N = 88 (fig.4).

It is impossible to assign quantum numbers to the excited states above the level at 1326.5 keV. From the logft values of the β decay of $^{144}$Cs feeding the low energy levels of $^{144}$Ba (first forbidden β-branches), the ground state of $^{144}$Cs can be assumed to be $2^-$ or $3^-$. This assignment is in accordance with the shell-model picture for even-even nuclei in this region : coupling of an $f_{7/2}$ neutron with a $g_{7/2}^+$ or $d_{5/2}^+$ proton. These configurations $pn^{-2}$ are in strong interaction and we can expect a great number of levels with negative parity and low spin near the ground state of $^{144}$Cs.

### 4.2 Decay scheme of $^{144}$La

Like in the decay of $^{144}$Cs only the low energy levels of $^{144}$Ce can be discussed. The first excited state at 397.3 keV is assumed to have $J^\pi = 2^+$ and would then be the one phonon vibrational state already seen by Cheifetz et al.[14]).

According to the systematic for the neighbouring Z = 58 and N = 86 nuclei (fig.6) the states at 938.4 and 1242.0 keV can be respectively assigned $J^\pi = 4^+$ and $3^-$. This assumption is supported by the absence of crosswer to the ground state. A $2^+$ assignment is given to the 1102.7 keV level which is deexcited by two γ-rays to the ground state and the first $2^+$ excited state.

The level at 1523.3 keV is probably

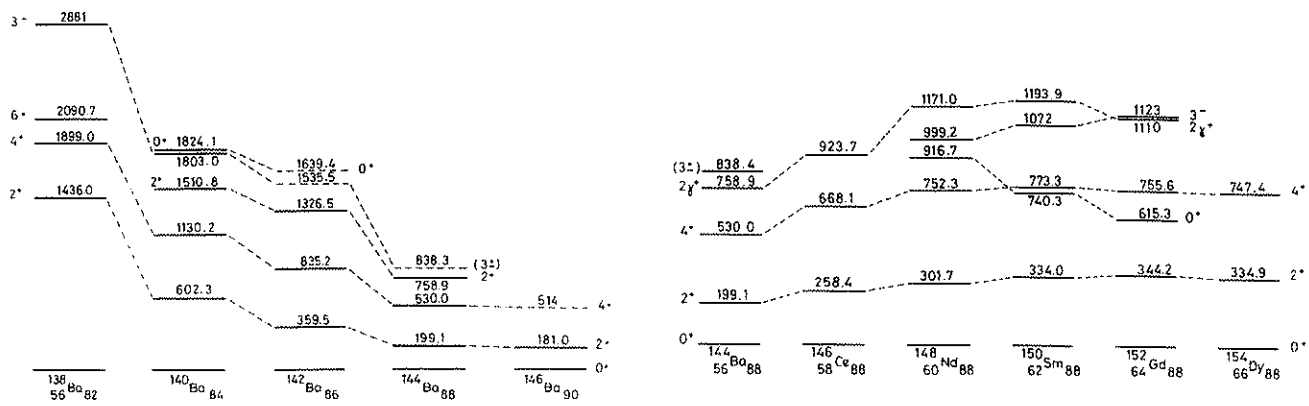


FIG.4 The lower-energy levels of Z = 56 (left curve) and N = 88 (right curve) nuclides.

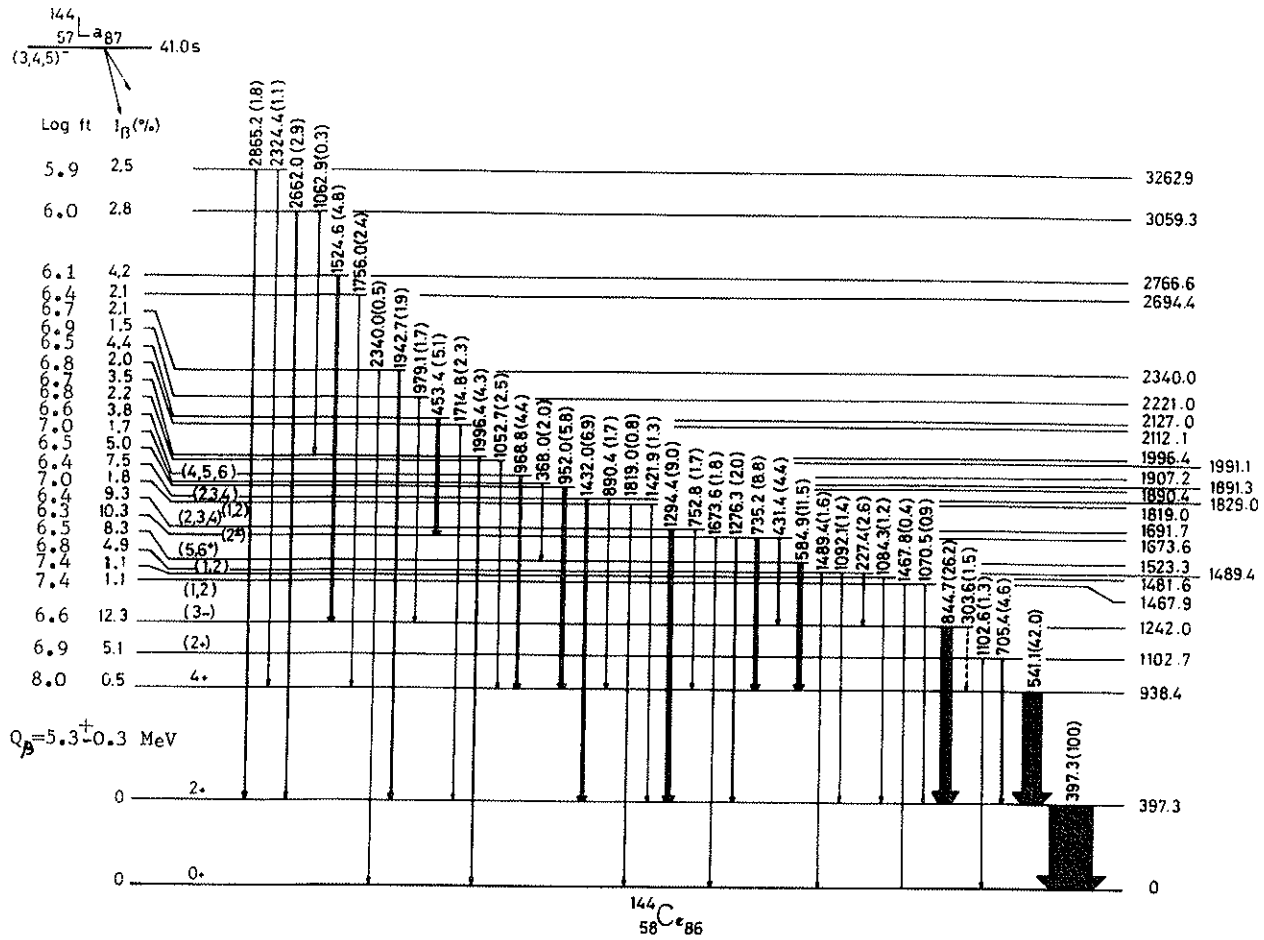


FIG.5 Energy levels and transitions in $^{144}$Ce. Logft values have been determined from the intensity balance of each level, assuming a negligible β feeding to the ground state and using a total decay energy of 5.3 MeV.

the $6^+$ excited state of the ground state band, since it is deexcited only by the 584.9 keV transition to the $4^+$ level at 938.4 keV. Moreover the energy of this state agrees with the value predicted by the variable moment of inertia (VMI) model of Mariscotti et al.[16].

From the β-feeding of the high spin levels of $^{144}$Ce and logft values, we can deduce that the ground state of $^{144}$La is assumed to have high spin (⩾ 3) with negative parity, therefore the ground state level of $^{144}$Ce is not fed in the $^{144}$La-decay.

## 5. Conclusion

It is evident that more experimental information is needed for all three nuclei to establish the nature of the individual levels. In addition to possible refinement and extension of the measurements reported here, studies of β-decay modes, internal-conversion processes, and directional correlations are needed. A precise explanation of the caracter of these nuclei is not possible at present. However, the very crude results for the even-even $^{144}$Ba and $^{144}$Ce nuclei show that new interactions become

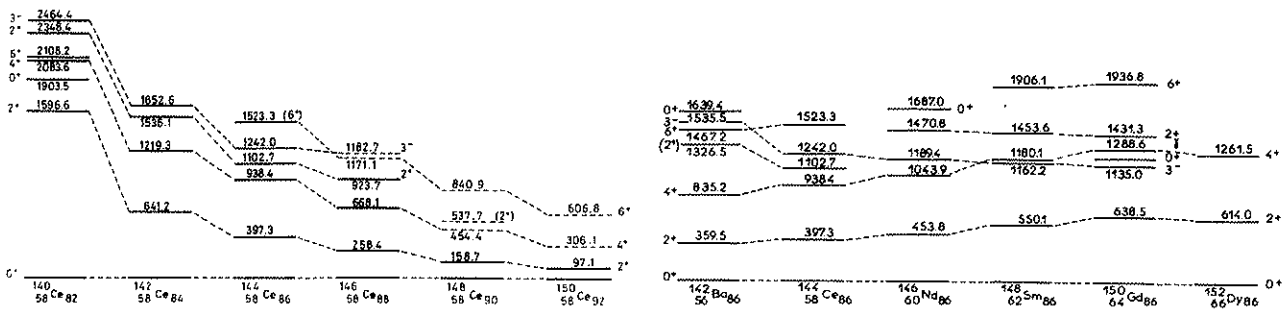


FIG.6 The lower-energy levels of Z = 58 (left curve) and N = 86 (right curve) nuclides.

important in these nuclei, especially in $^{144}$Ba where we can see low energy levels $2^+$, $4^+$, $2'^+$ and $3^-$ decrease very quickly compared with identical levels in $^{142}$Ba with N = 86 (fig.4a). Moreover in fig.7, the behaviour of the $E4^+/E2^+$ ratio, seems to indicate, for N = 88 nuclei, an increase of deformation with decreasing Z at less up to Z = 56, whereas for N = 86 nuclei, the deformation seems to decrease with decreasing Z after a maximum value for Z = 58.

Besides the present work, the informations included in the systematics of fig.4, 6 and 7 are obtained from ref.[14,15,17-19]

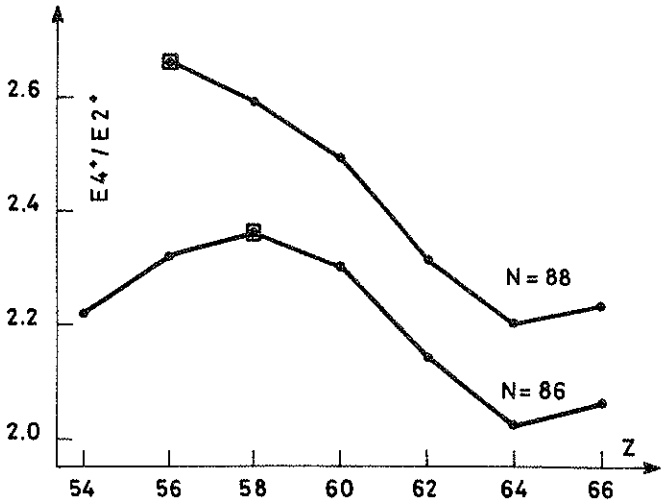


FIG.7 Systematic behavior of the ratio $E4^+/E2^+$ as a function of proton number for N = 86 and 88 nuclei. Data presented as ⊡ are from the present work and the other data are from ref.[14,15,17-19]

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