THE TRANSITIONAL CERIUM ISOTOPES $^{142,144}$Ce

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Abstract

The levels populated in $^{142,144}$Ce and the $\gamma$-ray transitions between these levels have been studied by the $\gamma\gamma$-directional correlation method following the $\beta$-decay of $^{142,144}$La. Coincidences were measured at six angles by Ge(Li) detectors operating in the event-by-event mode.

Coincidence data were analysed for selected gates and formed the basis for constructing extensive decay schemes. The directional correlation results enabled spin assignments to be made to most levels and the multipole mixing ratios of many transitions were determined.

1 Introduction

Lying between the semi-empic $^{144}$Ce(N = 82) nucleus and $^{146}$Ce which begins to show the characteristic level structure of a rotational nucleus, we have a group of nuclei in a transitional region. Their low-lying levels and the transitions linking these may be studied through the $\gamma$-ray transitions which occur following the $\beta$-decay of the parent lanthanum isotopes. These are conveniently produced in the mass-chains of the caesium fission products which are produced following thermal neutron capture by $^{233}$U. The 142, 144 and 146 mass caesium isotopes were selected by the OSTIS on-line separator at the ILL Grenoble and in this paper we report briefly on off-line measurements on levels and $\gamma$-ray transitions in $^{142,144}$Ce.

The principle features of the experiment were similar to those used by Scott et al [1] in measurements on the neutron-rich even-mass barium isotopes in which the caesium decays were studied in the on-line mode. In the present experiments the measurements were made in an off-line position approximately 20 cm from the isotope collection point. This separation assured that the isotope collection point. This period between tape transports was chosen to optimise the ratio of lanthanum activity to those of preceeding shorter-lived decays.

Gamma rays were detected by two 20% efficient Ge(Li) detectors and the source-detector separations were each 6 cm which ensured a relatively good coincidence efficiency without greatly decreasing the directional sensitivity of the system. The correlation table was automatically controlled and measurements were made at 6 angles approximately evenly spaced between 90° and 180°. The activity was monitored by the stationary detector and corrections were applied for changes in source strength and source decay and for the small miscentering of the source with respect to the moving detector.

Data were recorded in the event-by-event mode and the output of the TAC was also digitised. In the subsequent analysis it was possible to set gates corresponding to true-plus-accidental and accidental events and the spectrum of true events was obtained from the difference in these two spectra.

2. Data evaluation

2.1 Coincidence data

The coincidence data recorded at all angles were summed to give the total or 'global' spectrum for each decay. These spectra differ from the singles spectra as all non-coincident $\gamma$-ray transitions to the ground state are absent.

A selection of gating transitions was made and the coincidence spectra corrected for accidental and background were obtained. These spectra formed the basis for constructing the decay schemes.

Level energies were determined from the $\gamma$-ray energies and when a level had several alternative and established decay modes it was required that the total decay energies were consistent within the quoted errors. Errors arose partly from the energy calibration, which was made using $^{152}$Ba, but mostly from the analysis of the spectrum. We further required that the population and decay of a level was consistent with transition intensities. As a result of these conditions multiple placements of transitions are possible in only a few cases and these are indicated in the decay schemes.

2.2 Directional correlation data

Peak intensities were evaluated for the most intense transitions in coincidence with $\gamma$-rays which have a usefully large correlation coefficient. Corrections were made for the background contributions and for source miscentering and we obtained $a_\Lambda \gamma$, correlation coefficients in the equation

$$W(\theta) = 1 + a_\Lambda \gamma (P_{\Lambda} \cos\theta) + a_4 (P_4 \cos\theta)$$

where $a_\Lambda \gamma = B_\Lambda A_\Lambda$ and the $B_\Lambda$ and $A_\Lambda$ describe the first and second members of the cascade.

In total 2 x $10^7$ coincidence events were recorded for $^{142}$Ce and 4 x $10^7$ coincidences for $^{144}$Ce and in many of the evaluate correlations the statistical precision of the results was high as may be judged from Fig 6. Several assumptions were made in the data evaluation:

Levels decaying to the $0^+$ ground state have possible spin-parity assignments of $1^-$ or $2^+$. A transition with an $L = 2$ intensity greater than 10% is $E2$ and links states of the same parity. The converse statement is not always true but tentatively, and if not prevented by strong reasons a predominantly $L = 1$ transition is considered to be $E1$.

Spin assignments and mixing ratios were made at the level of one standard deviation on the $a_\Lambda \gamma$-coefficient.

The sign convention of Steffen and Alder [2] was used in the evaluation of multipole mixing ratios.
3 Experimental results

3.1 Levels and transition in $^{142}\text{Ce}$

Our previous knowledge of the decay of $^{142}\text{La}$ is summarised in Tables of Isotopes\(^1\)) and Nuclear Data Sheets\(^2\)) and the several earlier experiments indicate that the decay is complex with spin assignments made to only the first few levels and most $\gamma$-rays were unplaced in the scheme.

![Fig 1](image1) The single $\gamma$-ray spectrum of transition in $^{142}\text{Ce}$ following the $\beta$-decay of $^{142}\text{La}$.

Figs 1 - 4 show the $\gamma$-ray singles spectrum, the total coincidence spectrum, and examples of gated spectra. Altogether seven gates were used and on the basis of these data the level scheme shown in Figs 5a,b was constructed.

Only the 2043.4 keV level is in some doubt for although a 1402.2 - 641.2 keV coincidence was noted no other transition from the level was seen.

The 641.2 keV $2^+ - 0^+$ ground-state transition has a usefully large $A_r$ coefficient and all correlations were recorded in coincidence with this gate. Figure 6 show some of these results on plots of the coefficients $B_2$ vs $B_4$ as a function of the $I-1:L$ mixing ratio. An extensive discussion of all levels is given by Michelakakis\(^3\).

It should be noted that the 1219.3 keV level previously considered to be $4^+$ is $2^+$. The $a_2$-correlation result lies at approximately six standard deviations from the value for $a_4 - a_2 - 0$ cascade. This spin $2^+$ assignment now allows the 1303.7 keV transition to populate the level from the 2542.7 keV $1^-$ state as shown by the coincidence data and the $I=1$ character of the latter is given by the correlation data.

A possible $4^+$ level occurs at 1280.7 keV and is indicated by the presence of a weak 639.5 keV peak in the spectrum coincident with the 641.2 keV $2^+ \rightarrow 0^+$ transition and with no other one. Its weakness arises because direct feeding from $^{142}\text{La}$ is unlikely as it would be via a $\Delta I = 2$ first forbidden transition and similarly $\gamma$-ray feeding from higher lying low spin states is also improbable.

The results of the correlation measurements are summarised on the decay scheme and the extensive multipole mixing ratio data is contained in Michelakakis\(^3\).

![Fig 2](image2) The spectrum of coincident $\gamma$-rays obtained by summing the correlation data measured at six angles. It contains all $\gamma$-rays which are in coincidence with another transition.

![Fig 3](image3) The spectrum of $\gamma$-rays in coincidence with the 641.2 keV gate. The background and accidental contributions have been subtracted.

![Fig 4](image4) The spectrum of $\gamma$-rays in coincidence with the 578.1 keV gate. The background and accidental contributions have been subtracted.
Fig 5a The lower energy section of the level scheme in $^{142}\text{Ce}$
This new decay scheme of $^{112}$Ce contains 20 additional levels and allows the 40 previously identified but unplaced transitions to be located and in addition some 40 transitions have been identified for the first time. Spins have been assigned to 20 levels and the multipolarity of 30 transitions determined.

Fig 6 A plot of the $B_2$ and $B_4$ correlation coefficients as a function of the $L+1: L$ mixing ratio for different spin sequences. The result for the 578.1 – 641.2 keV correlation is labelled 1.

3.2 Levels and transitions in $^{114}$Ce

A summary of data from previous experiments shows that the decay scheme is complex and extensive and thus considerable care must be taken in the analysis of spectra.

The presence of preceding decays in the mass 144 chain was identified in the singles spectrum by the presence of the 103.9 keV $\gamma$-ray in $^{143}$La and the 199.4 keV transition in $^{142}$Ba. These had intensities of 4.6% and 0.12% respectively relative to the 397.9 keV 2 – 0 ground-state $\gamma$-ray in $^{114}$Ce.

Fig 8 The singles $\gamma$-ray spectrum of transitions in $^{114}$Ce following the $\beta$-decay of $^{114}$La.

Fig 9 The 'global' coincident $\gamma$-ray spectrum of $^{114}$Ce.

Fig 10 The spectrum of $\gamma$-rays coincident with the 397.3 keV gate.

Fig 11 The spectrum of $\gamma$-rays coincident with the 541.1 keV gate.
Fig 7 The decay scheme of $^{146}\text{Ce}$. Transition intensities are indicated.
Thirteen gates were used in the analysis and subsequently several of these were shown to contain unresolved components. Thus in this experiment it was particularly important to measure γ-ray relative intensities in the various gated spectra. The decay scheme based on this work is shown in Fig 7 and the relative intensities of γ-rays are included.

In Figs 8 - 11 we show examples of singles and coincident γ-ray spectra.

Before the present work only the first two excited states had firm spin parity assignments and these were based on IC data. The coincidence data allowed many correlations to be measured and the 397.3 and 541.1 keV gates could be usefully used. Again a full summary of the data is contained in Michelakis3).

This study of 115Ce has revealed about eighty additional γ-rays and thirty-seven new levels. It has also lead to a considerable revision of previous data. Spins have been assigned to more than forty levels and the multipole character of a similar number of γ-rays has been made.

3.2.1 The Qγ value of 119La

Previous measurements of the Qγ value by Stippier et al.13 were based on a decay scheme which differs in many respects from the present one. In particular the low lying levels have many alternative γ-ray feeding modes and thus contain a large number of γ-ray components and are perhaps not so suitable. If the 1523.5 keV γ-ray is used as the gating transition we may expect this to provide the greatest purity γ-spectrum as it comes from the decay of the 3197.2 keV level (see Fig 12). Previously it had been assumed to come from the decay of the 2767 keV level. We obtain, using the data of Stippier et al. the result Qγ = 5882 ± 180 keV and this is in good agreement with the value Qγ = 5820 keV based on the mass formulae of Liran and Zeldes2) and is contrary to the previous conclusion about the most appropriate mass formulae for this region.

4 Discussion

The two decay schemes show differences in their general features. In 114Ce there is a preponderance of low spin states while in 115Ce there are few, and only one 0+ state has been identified. These differences are thought to arise from the selectivity of the β-decay process and are due to the different spins of the parent lanthanum nuclei;

Iγ(112La) = 2− and Iγ(114La) = 4+ or 5−,

rather than from a fundamental change in level structure.

The level structures differ in one important aspect as may be seen in Fig 13. The second excited state in 114Ce has a spin-parity of 2− rather than 4+ which is common to the other cerium isotopes and also to the neighbouring N = 84 isotopes, 112Ba and 112Nd. We have weak evidence that a 4+ level occurs at 1280.7 keV.

The general trend in the relative energies of the 1− and 3− levels with increasing neutron number and the tendency to a rotational-like level structure is similar to that observed in barium isotopes by Scott et al. The interchange of the 1− and 3− levels again occurs between N = 86 and N = 88 and the 2g9/2 level continues to fall in energy in cerium as the neutron number increases but unfortunately the position of the 0γ level in the N = 88 and N = 90 isotopes is still unknown. These features suggest that we might interpret the cerium data in a similar way to that adopted for the group of barium isotopes and conclude that in cerium the onset of nuclear deformation occurs between N = 86 and N = 88 although it is apparent that 118Ce, like 118Ba, is not a good rotational nucleus.

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