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ABSTRACT

The directional correlations of coincident γ-transitions in ^{134}Xe have been measured using a Ge(Li)-NaI(T1) spectrometer. Spin assignments have been made for the levels at 1920 (3^+), 2136 (5^+), 2272 (4^+), 2352 (4^+), 2408 (5^+), 2588 (4^+) and 2867 keV (4^+). In addition previous spin assignments of levels at 1613 (2^+) and 1731 keV (4^+) have also been confirmed. The multipole mixing ratios δ(E2/M1) obtained from the present data are: $\delta(405) = 0.80 \pm ^{0.1}_{0.4}$, $\delta(433) = 0.08 \pm 0.06$, $\delta(540) = -1.92 \pm 0.1$, $\delta(595) = -0.32 \pm 0.20$, $\delta(621) = -0.76 \pm 0.05$, $\delta(677) = -0.32 \pm 0.02$, $\delta(766) = -2.4 \pm 0.2$, $\delta(857) = -0.64 \pm 0.1$, $\delta(948) = -0.40 \pm 0.10$, $\delta(1072) = -0.16 \pm 0.02$ and $\delta(1136) = 0.48 \pm 0.02$.

E | RADIOACTIVITY ^{134}I [from fission of U]; measured $\gamma\gamma(\theta)$. ^{134}Xe levels deduced J, π, δ.

1. Introduction

Although it appears that vibrational aspects do play an important role in the description of the first few excited states in doubly even nuclei in the mass region $100 < A < 150$, the interpretation of the excited states in terms of collective vibrations about a spherical equilibrium shape or in terms of quasi-rotational bands is unsatisfactory. In particular it is unable to account for the substantial magnetic dipole admixtures that have been observed in the γ-transitions between the vibrational states. Attemps to understand the large M1 admixtures in γ-transitions in these nuclei have been made by several workers[7,8,11].

The most succesful approach towards an understanding of the structure and properties of the nuclear states in quasi-spherical and quasi-deformed regions has been made by Kunar and Baranger[3,4,13-16] who have carried out extensive calculations for the nuclei in the mass region $182 \leqslant A \leqslant 196$ on the basis of the pairing plus quadruple force model. The E2/M1 mixing ratios predicted by the model in this region agree well with the experimental results. Similar calculations in the $A \approx 130$ region are not yet available and would probably have to take into account the coupling with the quasi-particle states. However, a systematic investigation of the E2/M1 mixing ratios is of considerable importance in providing a better understanding of the structure of these nuclei.

The excited states of ^{134}Xe have been studied by several workers in the past form the β-decay of ^{134}I. The first study of the γ-rays in the decay of ^{134}I was reported by McKeown and Katcoff[18]. Later, Johnson et al.[9] carried out investigations using scintillation detectors and coincidence techniques. Recently, detailed studies making use of high resolution γ-ray and electron-conversion spectrometers have been reported[1,19,21]. These studied have resulted in a reasonably complete level scheme of ^{134}Xe.

Takekoshi et al.[19] measured the anisotropy of the 884-847, 1072-847 and 1136-884-847 keV γ-cascades in the only previous measurement of directional correlations. The present investigation was undertaken with a view to measure the γ-γ directional correlations for several γ-cascades to elucidate the nature of the excited states in ^{134}Xe and in addition it was desired to obtain the values of the multipole mixing ratios δ(E2/M1) for a large number of γ-transitions in this nucleus. Due to the relatively short half-life of the source (53 min) the measurements were carried out at only four angles. However, an improved counting statistics is expected to compensate for the lesser number of angular positions included. The γ-γ coincidences were recorded at angles from 90° to 270° in steps of 30°.

2. Experimental

The radioactive source of ^{134}I was prepared by chemically separating the tellurium activity from the fission products of uranium and later milking iodine produced from the decay of tellurium. Approximately 300 mg of uranyl carbonate were irradiated with neutrons for 15 min in the reactor of the Instituto de Energia Atômica. The tellurium activity was separated soon after irradiation using the method described by Leddicotte[17]. The tellurium metal was finally dissolved in a drop of HNO_3^- and the solution was made alkaline with NH_4OH. The iodide carrier was added to this solution and the iodine activity was allowed to grow for a period of 1 h, then separated from tellurium following the method of Kleinberg and Cowan[10]. The dilute solution containing ^{134}I was transferred to a lucite container, the final source dimensions being 2 mm x 1.5 mm.

The γ-γ spectrometer employed the combination of a 35 cm^3 true-coaxial Ge(Li) detector and a 7.6 x 7.6 cm NaI(Tl) detector. The γ-γ coincidences were recorded using a standard fast coincidence system and a 4096 channel pulse-height analyzer. The memory of the analyzer was divided into four 1024 channel subgroups to accumulate spectra at four angles. The moving NaI(Tl) detector automatically changed angles every 10 min, routing the coincidence spectrum through the Ge(Li) detector to the proper subgroup of the analyzer. The counting with a single source was continued through a period of 2½ h. A total of 24 sources was used for the entire experiment.

The SCA window was set to accept the combined photopeaks at the 847, 857 and 884 keV in the NaI(T1) detector spectrum. The effects of Compton scattered radiation of higher energy γ-rays included in the window were in most cases negligible. However in a few cases these effects were easily estimated and taken into account. The intensities of the coincident γ-rays were measured from the Ge(Li) detector spectra recorded at various angle and corrected for the chance coincidences (< 2%) and for the source decay. The angular correlation coefficients A_{kk} were obtained by a least square fitting procedure in the usual manner. The convention of Becker and Steffen[5] has been accepted for the phase of the multipole admixture δ.

Since both 847 keV and 884 keV γ-transitions are included in the gating window, the angular correlation coefficients measured for γ-rays which de-excite through the 884-847 keV cascade are the combination of two correlations $A_k(\gamma)A_k$(884 keV) and $A_k(\gamma)U_k$(884 keV)A_k(847 keV). However, since a spin sequence of 4^+-2^+-0^+ is well confirmed for the 884-847 keV γ-cascade the two correlations are identical because $F_k(2, 2, 4, 2) = U_k(4, 2)F_k(2, 2, 2, 0)$.

3. Results

The low energy γ-ray spectrum in the decay of ^{134}I obtained with the Ge(Li) detector is shown in fig. 1. The spectrum shows all the γ-rays of ^{134}I observed by Winn and Sarantites[21] in this energy region. The intensities of the γ-rays from $^{132,133,135}I$, relative to ^{134}I, however, are lower in the spectra from the sources used in the present study. A typical γ-ray spectrum observed in coincidence with the combined 847 keV and 884 keV photopeaks is also shown in fig. 1.

The results for the directional correlations coefficients A_{KK} obtained from the present measurements for various γ-cascades are given in table 1. The experimental values of A_{KK} have been corrected for the finite-solid-angle effects of the detectors[6,22]. The multipole mixing ratios δ for the γ-transitions, together with the spin sequence consistent with the observed correlation data and the decay properties, are presented in table 2. The value of δ in each case was determined from the χ^2 plot against δ-values.

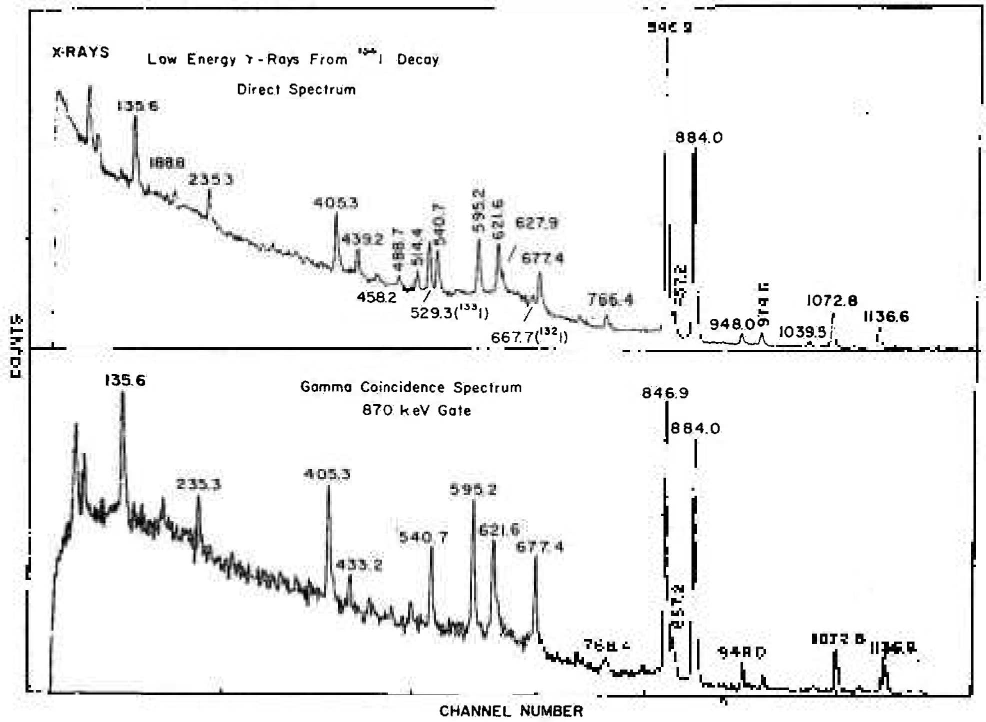

Fig. 1. Direct low energy γ-ray spectrum in the decay of ^{134}I observed with the Ge(Li) detector and the γ-ray spectrum coincident with combined 884, 857 and 847 keV photopeaks.

The parametric plots for some of the relevant spin sequences are shown in fig. 2. The corrected values of A_{KK} with associated errors have been displayed as (A_{22}, A_{44}) points in this plot. A partial energy level scheme of ^{134}Xe is shown in fig. 3. Only the γ-transitions of interest in this study are shown. The spin and parity assigments deduced from the present investigation have been included in this figure.

Table 1

Results of directional correlation measurements of transitions in ^{134}Xe

	Gamma cascade	A_{22}	A_{44}
	136-(405)-884-847	0.158 ± 0.063	0.022 ± 0.095
(a)	405-884-847	0.031 ± 0.022	−0.048 ± 0.032
	433-(1072)-847	−0.004 ± 0.070	0.250 ± 0.105
(b)	540-884-847	0.076 ± 0.011	0.139 ± 0.014
	595-(540)-884-847	−0.186 ± 0.024	0.042 ± 0.035
(c)	621-884-847	0.218 ± 0.015	0.050 ± 0.022
(d)	677-884-847	−0.261 ± 0.023	−0.058 ± 0.033
(e)	766-847	0.220 ± 0.043	0.062 ± 0.065
(f)	857-884-847	0.252 ± 0.009	0.125 ± 0.022
	884-847	0.096 ± 0.007	0.019 ± 0.010
	948-(1072)-847	−0.328 ± 0.046	0.115 ± 0.066
(g)	1072-847	0.051 ± 0.009	−0.012 ± 0.013
(h)	1136-884-847	0.023 ± 0.003	0.056 ± 0.005

Table 2

Multipole mixing ratios of γ-transitions in ^{134}Xe

Energy level (keV)	γ-cascade	Mixed transition	Possible spin sequence	Mixing ratio δ(E2/M1)
1613	766-847	766	2(1,2)2(2)0	−2.4 ± 0.2
1920	1072-847	1072	3(1,2)2(2)0	0.16 ± 0.02
2136	405-884-847	405	5(1,2)4(2)2(2)0	$0.80 \pm^{0.7}_{0.4}$
2272	540-884-847	540	4(1,2)4(2)2(2)0	−1.92 ± 0.1
2353	621-884-847	621	4(1,2)4(2)2(2)0	−0.76 ± 0.05
2353	433-(1072)-847	433	4(1,2)3(1,2)2(2)0	0.08 ± 0.06
2408	677-884-847	677	5(1,2)4(2)2(2)0	−0.32 ± 0.02
2588	857-884-847	857	4(1,2)4(2)2(2)0	−0.64 ± 0.1
2867	1136-884-847	1136	4(1,2)4(2)2(2)0	0.48 ± 0.02
2867	948-(1072)-847	948	4(1,2)3(1,2)2(2)0	−0.40 ± 0.1
2867	595-(540)-884-847	595	4(1,2)4(1,2)4(2)2(2)0	−0.32 ± 0.20

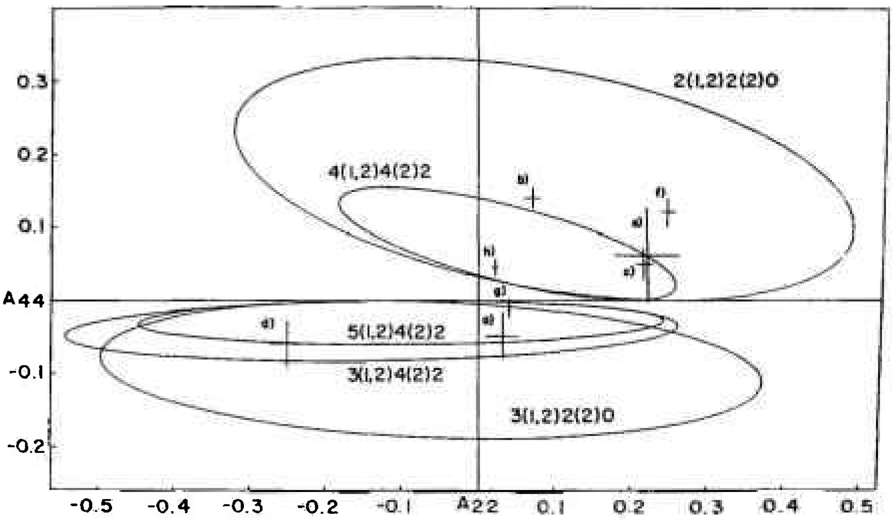

Fig. 2. Parametric plots for various spin sequences showing the experimental A_{22} and A_{44} points with error bars.

The results for the 884-847 keV cascade show good agreement with the A_{KK} coefficients expected for a 4-2-0 spin sequence. The spin and parity of the 1613 keV level is believed to be 2^+ considering the very small β-feeding ($\log ft > 9.5$) to this level[21] from the ground state of ^{134}I with spin 4 or 5. This assignment is also consistent with the systematics of levels in the neighbouring doubly even Xe isotopes, this level being considered as the member of a two-phonon triplet. The intensity of the 766 keV γ-ray was measured from the coincidence spectra at different angles to determine the directional correlation of the 766-847 keV cascade. The relative intensity of the 766 keV transition is however quite small which resulted in poor counting statistics. The A_{KK} values offer two solutions for the mixing ratio of the 766 keV transition ($\delta = 0.004$ and -2.4). The χ^2 analysis favors slightly the value of -2.4. The large values for similar $2_2^+ \rightarrow 2_1^+$ transitions in ^{126,128,132}Xe would also favor this value.

The A_{KK} values for the 1072-847 keV cascade are consistent only with a 3-2-0 spin sequence thus clearly establishing a spin of 3 for the 1920 keV level. The electron-conversion measurements[1] indicate that the 1072 keV transition to the 847 keV (2^+) state is of multipolarity M1-E2 suggesting positive parity for the 1920 keV state. The results for the 405-884-847 keV cascade indicate 5-4-2-0 and 3-4-2-0 as possible spin sequences. The spin value of 3 for the 2136 keV level is however unlikely due to the lack of any γ-transition from this state to either of the 2^+ states at 1613 keV and 847. The possibility of spin 6 for this level has been rejected since the analysis results in an unreasonably high M3 component for the 405 keV transition. Based on the measurement of the conversion coefficient of the 405 keV transition[1] (which is of M1-E2 character), the most probable spin assignment for the 2136 keV state is 5^+.

Previous decay studies[21] assigned spin 4, 5 or 6 for the 2272 keV state with either parity. The negative parity was eliminated from the α_K measurements on the 540 keV transition. Our results for the 540-884-847 keV cascade clearly indicate a spin of 4 for this level.

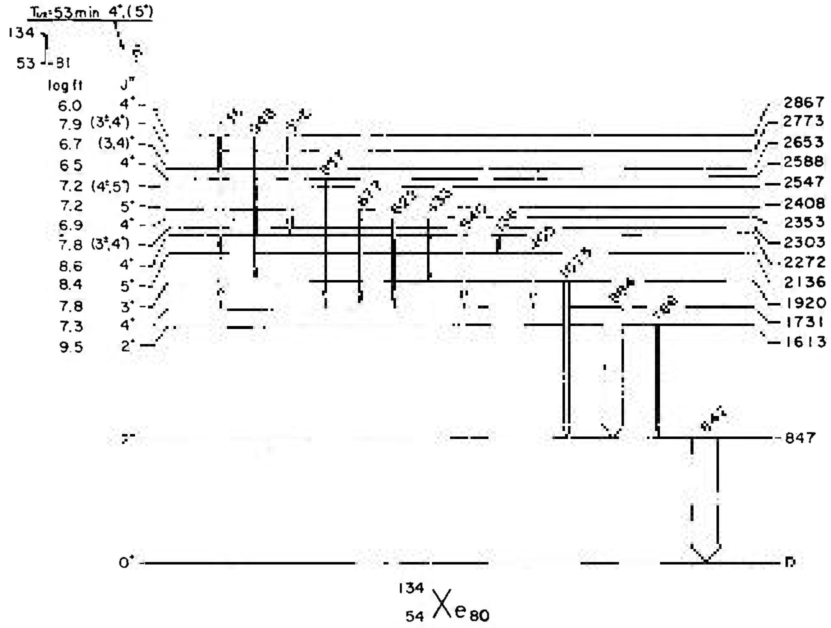

Fig. 3. Partial decay scheme of ^{134}I to levels in ^{134}Xe.

From earlier studies[1,21] the possible spins and parity of the 2352 keV level are restricted to 3^+ or 4^+. The present data on the 621-884-847 keV cascade show a preference for a spin value of 4. The results for the 433-(1072)-847 keV cascade also de-exciting this level were analyzed assuming spin 3 for the 1920 keV level and $\delta(1072) = 0.16$. Both spins 3 and 4 for the 2352 keV level are consistent with the measured A_{KK} for this correlation and the 433 keV transition is predominantly M1 with either choice.

The directional correlation results for the 677-884-847 keV cascade are consistent with both 5-4-2-0 and 3-4-2-0 spin sequences. A spin of 3 for the 2408 keV state can be ruled out considering the lack of γ-transitions to the lower 2^+ states. The electron-conversion measurements on the 677 keV transition is unable to eliminate either of the parity assignments.

The present directional angular correlation results for the 857-884-847 keV sequence combined with α_k measurements of the 235 keV and 612 keV transition[1] indicate spin 4^+ for the 2588 keV level. Earlier studies[21] suggested spin 3 or 4 for this state.

Three cascades 1136-884-847, 948-(1072)-847 and 595-(540)-884-847 keV de-exciting the 2867 keV level have been measured and should serve to define the spin of this level. Winn and Sarantites[21] proposed the spin and parity of this level to be 4^+ or 5^+ based upon the large β-feeding to this level. The anisotropy measurements of Takekoshi et al.[19] also indicate spins of 4 or 5. The positive parity for this level was later confirmed from the α_k measurements on the 595 keV and 540 keV transitions both of which are M1-E2 feeding positive-parity states. The A_{KK} coefficients for the 1136-884-847 keV cascade clearly indicate a spin of 4 for the level. The multipolarity of the 948 keV transition was calculated from the measured A_{KK} for the 948-(1072)-947 keV cascade. The choice of spin 5 was again ruled out since it resulted in a large M3 character for the transition. The mixing ratio of the 595 keV transition was similarly calculated from the measured A_{KK} values assuming $\delta(540) = -1.92$. The transition is > 90% M1 with the choice of spin 4^+ for the 2867 keV state. This result is in agreement with the α_K measurement on the 595 keV transition.

4. Discussion

The present investigation has yielded the E2/M1 mixing ratios for a number of γ-transitions in ^{134}Xe and has resolved several ambiguities regarding the spin assignments of the excited states. The mixing ratio of the 767 keV $2_2^+ \to 2_1^+$ transition was deduced to be -2.4 ± 0.2. The corresponding $2_2^+ \to 2_1^+$ transitions in ^{126}Xe($\delta = +9.1$) [ref.20] ^{128}Xe($\delta = +6.4$) [ref.2] ^{132}Xe($\delta = +5.3$) [ref.12] show somewhat larger quadupole contents and have all positive-δ values in contrast to ^{134}Xe. The smaller quadrupole content may be explained because of the higher energy of the 2_2^+ state in ^{134}Xe compared to other Xe nuclei (the energy of the 2_2^+ state rises from 880 keV in ^{126}Xe to 1613 keV in ^{134}Xe). As the energy of the 2_2^+, state increases the quasi-particle contribution to the state also presumably increases with the result that the state is expected to be less collective in ^{134}Xe. The γ-transition to the ground state is somewhat stronger than to the 2_1^+ (one-phonon) state. From the vibrational model one would expect the γ-transition changing phonon number by two units to be much reduced in intensity compared to that changing the phonon number by one unit.

It is noteworthy that the internal-conversion measurements indicate that none of the reasonably intense γ-transition in ^{134}Xe appear to be E1 in character. Thus no definite identification for the 3^- state corresponding to one octupole phonon has been made. A 0^+ member of the two-phonon triplet is missing, however this state is not expected to be populated from the (5^+, 4^+) ground state of ^{134}I. Hence it appears that an interpretation of the excited states of ^{134}Xe in terms of simple vibrational model is of limited value. More refined models which take into account the interactions between collective and quasi-particle effects may be needed to explain the structure of this nucleus.

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RÉSUMÉ

^{134}Xe été étudié par la methode de la corrélation angulaire directionalle de coincidence γ-γ, en utilisant le spectrométre Ge(Li)- NaI(Tl). On a determiné les valeurs des spins pous les niveaux suivants: 1920(3^+), 2136(5^+), 2272(4^+), 2352(4^+), 2408(5^+), 2588(4^+) et 2867 keV(4^+). Aussi les valeurs des spins pour les niveaux 1613(2^+) et 1731 keV(4^+) on étés confirmée. Les rapports de la mélonge multipolaire δ(E2/M1) trouvés dans cet travail sont les suivants: $\delta(405) = 0.80 {}^{+0.7}_{-0.4}$, $\delta(433) = 0.08 \pm 0.06$, $\delta(540) = -1.92 \pm 0.1$, $\delta(505) = -0.32 \pm 0.20$, $\delta(621) = -0.76 \pm 0.05$, $\delta(677) = -0.32 \pm 0.02$, $\delta(766) = -2.4 \pm 0.2$, $\delta(857) = -0.64 \pm 0.1$, $\delta(948) = -0.40 \pm 0.10$, $\delta(1072) = -0.16 \pm 0.02$ e $\delta(1136) = 0.48 \pm 0.02$.

RESUMO

A correlação direcional de coincidências gama em transições do ^{134}Xe foi medida utilizando um espectrômetro a Ge(Li) - NaI(Tl). Foram propostos spins para os níveis 1920(3^+), 2136(5^+), 2272(4^+), 2352(4^+), 2408(5^+), 2588(4^+) e 2867 keV(4^+). Em adição, foram confirmados os spins dos níveis a 1613(2^+) e 1731(4^+). As razões das misturas multipolares δ(E2/M1) obtidas no presente trabalho foram:

$\delta(405) = 0.80 \pm ^{0.7}_{0.4}$, $\delta(433) = 0.08 \pm 0.06$, $\delta(540) = -1.92 \pm 0.1$, $\delta(595) = -0,32 \pm 0.20$, $\delta(621) = -0.76 \pm 0.05$, $\delta(677) = 0.32 \pm 0.02$, $\delta(766) = -2.4 \pm 0.2$, $\delta(857) = -0.64 \pm 0.1$, $\delta(948) = -0.40 \pm 0.10$, $\delta(1072) = -16 \pm 0.02$ e $\delta(1136) = 0.48 \pm 0.02$.

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