Eur. Phys. J. A **7**, 177–180 (2000)

THE EUROPEAN
PHYSICAL JOURNAL A

Measurement of quadrupole moment of the 134 keV level in ^{131}Cs

C.C. Dey[1,a], B.K. Sinha[1], S.K. Das[2]

[1] Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Calcutta - 700 064, India
[2] Variable Energy Cyclotron Centre, 1/AF Bidhannagar, Calcutta - 700 064, India

Received: 21 October 1999 / Revised version: 22 December 1999
Communicated by D. Schwalm

Abstract. The time differential as well as time integral perturbed angular correlations of the 486-134 keV cascade in ^{131}Cs have been studied in a polycrystalline $BaSO_4$ powder source using a HPGe-BaF_2 detector system. The fundamental quadrupole frequency for the 134 keV level has been found to be $\omega_0 = (4.4 \pm 0.4)$ x10^7 rad/s. From a comparison of the quadrupole frequencies of this level and that of the 81 keV level in ^{133}Cs, measured earlier in the same crystalline environment of the source, the absolute value of the quadrupole moment of the 134 keV level in ^{131}Cs has been found to be 0.022 ±0.002 b. This value of the quadrupole moment is reported for the first time and compared with the value predicted theoretically within the unified nuclear model with intermediate coupling.

PACS. 23.20.En Angular distribution and correlation measurements – 21.10.Ky Electromagnetic moments – 27.60.+j $90 \leq A \leq 149$

1 Introduction

The unified nuclear model with intermediate coupling has been applied to understand the structure of the low-lying excited levels in odd-A $^{131-135}$Cs nuclei [1-3]. Such attempts were motivated by the fact that the Cesium nuclei fall within the so-called vibrational region. The intermediate coupling approach in the unified nuclear model has been successfully applied to explain the low-lying levels in a large number of nuclei in various mass regions. In these odd-A Cs nuclei the calculations [2] were performed by assuming a single odd proton having available two single particle states to be coupled to a vibrating core. The calculations by Choudhury et al. [3] were performed by assuming that either the last odd proton having available to it several single-particle states ($2d_{5/2}$, $1g_{7/2}$, $2d_{3/2}$), or the three-particle-hole state in the $1g_{7/2}$ subshell, which can undergo excitations, is coupled to the appropriate doubly even core. The ground and the first excited levels of these nuclei were well reproduced by this model [2,3]. The available data [4] of magnetic moments of these two levels in the above nuclei agree also with these calculations [1-3] (Table 1) although many experimental data for the low energy levels were not reproduced by this model. For example, both in ^{131,133}Cs nuclei, the levels with excitation energies below 450 keV, other than the ground and the first excited levels, were not reproduced by Freed et al. [2] (Fig. 1). In ^{131}Cs nucleus, Choudhury et al. [3] found a third excited level at 134 keV having a spin value of $3/2^+$ while the experimental spin value for the 134 keV level is $5/2^+$ [5]. Secondly, the calculations of the ground state quadrupole moments in ^{133,135}Cs nuclei disagree with the experimental values [4] (Table 1). In ^{135}Cs nucleus, the values of the quadrupole moment calculated by Kisslinger et al. [1] and Freed et al. [2] differ in magnitude as well as sign with the experimental result. In ^{133}Cs nucleus also, the calculations of quadrupole moments (Table 1) show

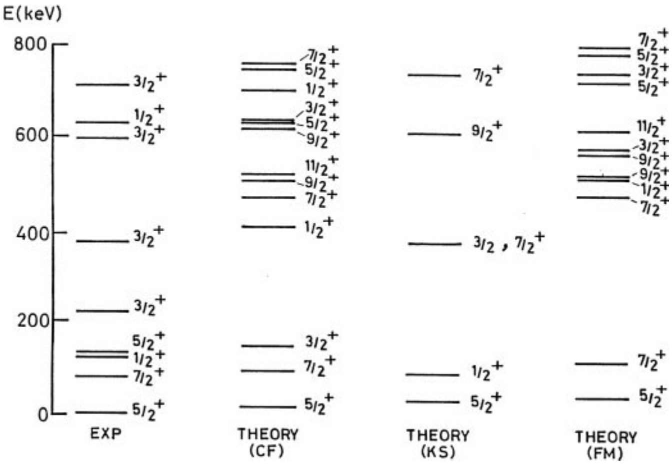

Fig. 1. The comparison of experimental and theoretical spectra of ^{131}Cs (up to 800 keV). The references are, Exp.[5], KS[1], FM[2], CF[3]

---

[a] correspondence to: ccd@hp2.saha.ernet.in

Table 1. Available values of experimental and theoretical quadrupole and magnetic moments in Cs nuclei

Nucleus	Level (keV)	Spin	Exp.Q(b) ([4])	Exp.μ(nm) ([4])	Theo.Q (b)	Theo. μ (nm)
^{131}Cs	g.s.	$5/2^+$	-0.575(6)	+3.543(2)	-1.04$^{a)}$	2.78$^{a)}$
					-0.40$^{b)}$	3.22$^{b)}$
					-0.49$^{c)}$	2.96$^{c)}$
	134	$5/2^+$	0.022(2)$^{d)}$	+1.86(8)	-0.32$^{c)}$	1.24$^{c)}$
^{133}Cs	g.s.	$7/2^+$	-0.00371(14)	+2.582	-0.31$^{a)}$	2.56$^{a)}$
					-0.72$^{b)}$	2.61$^{b)}$
					0.17$^{c)}$	2.43$^{c)}$
	81	$5/2^+$	-0.33(2)	+3.45(2)	-0.96$^{a)}$	3.03$^{a)}$
					-0.61$^{b)}$	3.11$^{b)}$
					+0.51$^{c)}$	2.15$^{c)}$
	161	$5/2^+$		+2.0(2)	-0.69$^{c)}$	3.98$^{c)}$
^{135}Cs	g.s.	$7/2^+$	+0.050(2)	+2.7324(2)	-0.12$^{a)}$	2.52$^{a)}$
					-1.11$^{b)}$	2.58$^{b)}$
					0.21$^{c)}$	2.60$^{c)}$

$^{a)}$ [1]
$^{b)}$ [2]
$^{c)}$ [3]
$^{d)}$ Present work, absolute value

that the ground state is deformed rather than spherical as found experimentally (Q ∼ 0). In ^{131}Cs nucleus only, the calculated values of ground state quadrupole moments [2,3] are found to be much closer to the experimental value (Table 1). For any of the excited levels in this nucleus, however, no experimental data of quadrupole moments are available [6] for comparison with the above model. The determination of quadrupole moments of excited levels is important to test the different nuclear models. It is hoped that the present experimental value of quadrupole moment will be helpful for understanding the structure of the 134 keV level.

The quadrupole moment of the 134 keV level in ^{131}Cs viz., Q(134 keV, ^{131}Cs) has been determined by the time differential as well as time integral perturbed angular correlation (PAC) studies of the 486-134 keV ($1/2^+ \rightarrow 5/2^+ \rightarrow 5/2^+$) cascade in a source of polycrystalline $BaSO_4$ powder. The quadrupole moment of the 134 keV level interacts with the electric field gradient in the source. The quadrupole interaction frequency ν_Q ($= eQV_{zz}/h$) is given by $\nu_Q = \omega_0 I(2I-1)/3\pi$ (for half-integral spin value I of the intermediate level), where, ω_0 is the fundamental quadrupole frequency and V_{zz} is the electric field gradient present in the source. The value of ω_0 has been determined from the integral measurement of G_2A_2 and also from the time differential measurement of $G_2A_2(t)$, where G_2 is the attenuation coefficient in the source due to quadrupole interaction. The value of Q(134 keV, ^{131}Cs) has been determined by comparing our measured value of ω_0 for this level with that of the 81 keV $5/2^+$ level in ^{133}Cs, measured earlier by Sharma et al. [7] in the same polycrystalline $BaSO_4$ powder source where the electric field gradient is expected to be the same. The ratio of quadrupole frequencies for these two levels equals the ratio of their quadrupole moments. Since the value of Q(81 keV, ^{133}Cs) is known [4], the value of Q(134 keV, ^{131}Cs) can be determined from the above ratio. In this ratio, the electric field gradient V_{zz} cancels out because of the same crystalline form of the source

2 Experimental details

The PAC studies of the 486-134 keV cascade in ^{131}Cs have been performed using a HPGe-BaF_2 detector system. The radioisotope ^{131}Ba in the form of $BaCl_2$ in HCl obtained from BRIT, Mumbai, India, has been converted into $BaSO_4$ crystal using the procedure described elsewhere [8]. A quantity of 0.2 gms $BaCl_2$ taken in 100 ml solution with 1 ml concentrated HCl is heated to boiling and then hot 0.5M H_2SO_4 is added slowly with constant stirring. The precipitate of $BaSO_4$ digested on steam bath for 3 hours is filtered, washed and dried. The polycrystalline $BaSO_4$ powder source thus prepared has been taken in a small perspex capsule and is placed at the centre of the HPGe and BaF_2 detectors which are at 7 and 10 cm, respectively, away from the source. The HPGe detector used is an ORTEC make (model no. GMX-20200, active volume 127 cm^3) having an energy resolution of 1.8 keV at 1 MeV γ -energy. The BaF_2 detector used is a 51 x 51 mm BaF_2 scintillator coupled to a Phillips XP2020Q photomultiplier tube. The 486 keV γ -ray has been detected in the HPGe detector and the composite (124 + 134) keV γ -rays have been detected in the BaF_2 detector. A clear separation of the 486 and 496 keV γ-rays (Fig. 2) in the HPGe detector helps to select the 486-134 keV cascade quite accurately although the BaF_2 detector can not seperate the close-lying 124 and 134 keV γ -rays. This is

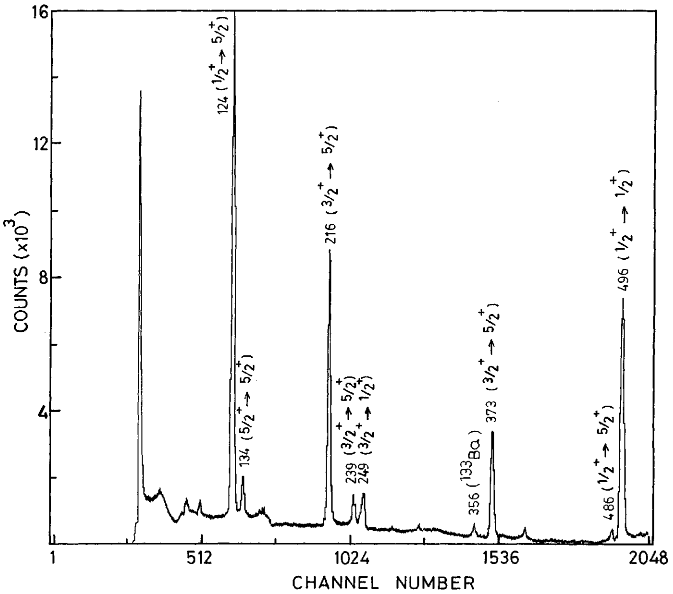

Fig. 2. Relevant portion of the γ -ray spectrum of ^{131}Cs in the HPGe detector. Energies of the γ lines shown are in keV

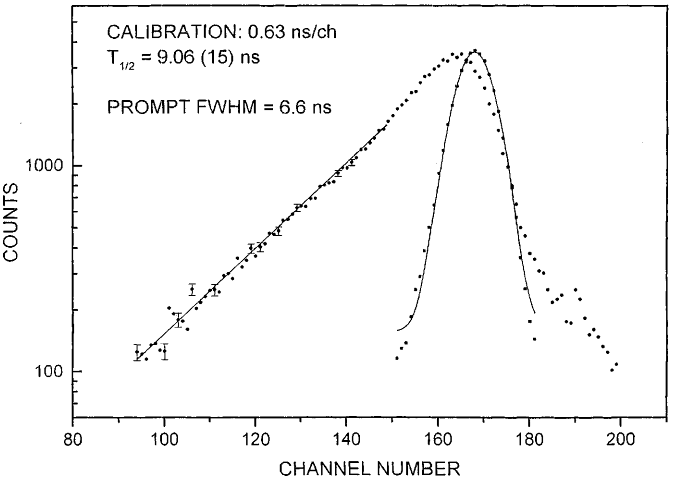

Fig. 3. The delayed coincidence spectrum of the 486-134 keV cascade of ^{131}Cs, measured in a source of $BaCl_2$ in HCl solution at $\theta = 120°$, showing the lifetime of the 134 keV level. The HPGe detector selects the 486 keV γ and the BaF_2 detector selects the composite (124 + 134) keV γ -rays. The corresponding prompt time spectrum taken with a ^{22}Na source for the same energy window settings is also shown in the figure

evident from the delayed coincidence spectrum (Fig. 3), taken using the above energy windows in the two detectors, which gives the lifetime of the 134 keV level. A small prompt contribution seems to be present here which may come through Compton-Compton coincidences of higher energy γ -rays. The prompt time resolution at these energies has been found to be 6.6 ns for this detector system. The data of PAC measurements of this cascade have been taken at the angles of 180° and 90°. The angles are altered at an interval of 30 minutes.

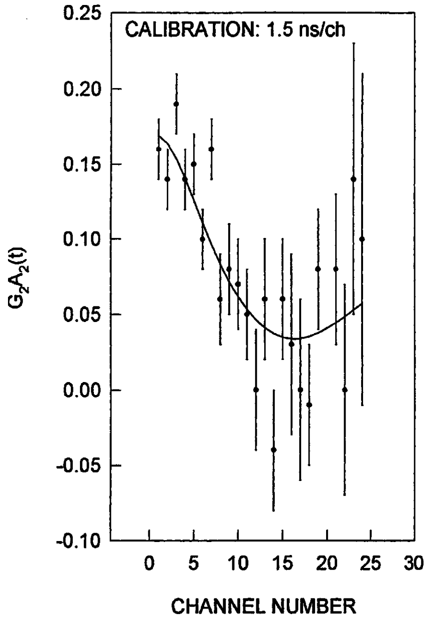

Fig. 4. The TDPAC spectrum of the 486-134 keV cascade in ^{131}Cs in a source of polycrystalline $BaSO_4$ powder. The solid line is the least squares fitted curve

3 Results and discussions

From the delayed coincidence spectrum of the 486-134 keV cascade the lifetime of the 134 keV level has been found to be $T_{1/2}$ = 9.06 ± 0.15 ns. This value of the half-life is in good agreement with the weighted average value ($T_{1/2}$ = 8.7 ± 0.6 ns) reported in the Nuclear Data Sheets [5]. The PAC studies of the 486-134 keV cascade have been performed from the measurement of the anisotropy W(180°)/W(90°), where W(180°) and W(90°) are the random subtracted counts at 180° and 90°. The values of $G_2A_2(t)$ at different time channels t are shown in Fig. 4. It is observed that the $G_2A_2(t)$ value near t = 0 channel is slightly lower than the unperturbed value 0.234 ± 0.011. This reduction of G_2A_2 value near t = 0 channel may be due to the prompt contribution. The least squares fitted values of ω_0 and η have been found to be $\omega_0 = (4.3 \pm 0.5)\mathrm{x}10^7$ rad/s and $\eta = 0.9 \pm 0.1$, where, η is the anisotropy parameter. This value of η is very close to that reported by Sharma et al. [7] ($\eta = 0.7$) for the same crystal structure of the source. In the TDPAC spectrum, the statistics of the data points is poor which is difficult to improve because of the weak nature of the cascade. We have measured also the value of ω_0 from the integral PAC study. Our integral angular correlation measurement in the polycrystalline $BaSO_4$ powder source gives a value of G_2A_2 = 0.13 ± 0.01. To determine the integral value of G_2 in this source we have measured the angular correlation of the 486-134 cascade in ^{131}Cs in a liquid source of $BaCl_2$ in HCl using the above detector system. The unperturbed angular correlation coefficients have been found to be $A_2 = 0.234 \pm 0.011$ and $A_4 \sim 0$ [9]. Thus, from our measured value of G_2A_2 in the $BaSO_4$ source, an integral attenuation factor $G_2 = 0.55 \pm 0.05$ has been obtained.

The crystal structure of $BaSO_4$ is known to be rhombic. The above value of G_2 corresponds to a value of $\omega_0\tau/\pi$ = 0.20 ± 0.03 [10] for a rhombic quadrupole interaction in a polycrystalline source (for the value of η = 0.9). Here, τ is the mean lifetime of the intermediate level. For the present measured value of τ = 13.1 ± 0.2 ns for the 134 keV level, the value of ω_0 has been found to be (4.7 ± 0.6)x10^7 rad/s. This value of ω_0 is in good agreement with the value obtained from our TDPAC measurement which shows consistency in our measurements. An weighted average value of ω_0 obtained from both these measurements has been found to be ω_0 = (4.4 ± 0.4)x10^7 rad/s corresponding to a value of ν_Q(134 keV, ^{131}Cs) = 47 ± 4 MHz at room temperature. In the same chemical form of the source, a value of ν_Q(81 keV, ^{133}Cs) = 700 MHz was reported by Sharma et al. [7]. Thus, the ratio of ν_Q(134 keV, ^{131}Cs) and ν_Q(81 keV, ^{133}Cs) has been found to be 0.067 ± 0.006, considering an error in ν_Q(134 keV, ^{131}Cs) only. The value of Q(81 keV, ^{133}Cs) has been reported to be -0.33 ± 0.02 b [4]. Using this value of Q(81 keV, ^{133}Cs), the absolute value of the quadrupole moment of the 134 keV level in ^{131}Cs comes out to be Q(134 keV, ^{131}Cs) = 0.022 ± 0.002 b. In the calculation of error in Q(134 keV, ^{131}Cs), only the error in ν_Q(134 keV, ^{131}Cs) has been considered, since the error in ν_Q(81 keV, ^{133}Cs) was not quoted in [7]. Thus, the actual error in Q(134 keV, ^{131}Cs) may be somewhat larger than the above quoted value.

The theoretical value of Q(134 keV, ^{131}Cs) has been computed by Choudhury et al. [3] to be Q = -0.32 b (assuming $e_p{}^*$ = e_p, e_p and $e_p{}^*$ are the free and effective nucleon charges) which is almost an order of magnitude higher than our experimental value. The theoretical value of the magnetic moment of the 134 keV level in ^{131}Cs (1.24 μ_N with $g_s{}^*$ = g_s, g_s and $g_s{}^*$ are the free and effective values of the spin gyromagnetic ratio) is, however, close to the experimental value (1.86 ± 0.08 μ_N) [4]. The magnetic moments of the ground and first excited levels in the odd-A $^{131-135}$Cs nuclei agree also with the unified model calculations [1-3] unlike the quadrupole moments. Thus, we can conclude that although the magnetic moments of the low-lying levels in odd-A $^{131-135}$Cs nuclei agree with the unified model calculations [1-3], the quadrupole moments in these nuclei do not agree with the above model.

References

1. L.S. Kisslinger and R.A. Sorensen: *Rev. Mod. Phys.*, **35**, 853 (1963)
2. N. Freed and W. Miles: *Nuovo Cimento*, **60B**, 301 (1969)
3. D.C. Choudhury and J.N. Friedman: *Phys. Rev.C*, **3**, 1619 (1971)
4. P. Raghavan: *At. Data Nucl. Data Tables*, **42**, 189 (1989)
5. Yu.V. Seregeenkov, Yu.L. Khazov, T.W. Burrows and M.R. Bhat: *Nucl. Data Sheets*, **72** 487 (1994)
6. R.B. Firestone and V.S. Shirley: *Table of Isotopes*, 8th Edn. New York: John Wiley and sons 1996
7. R.P. Sharma, M.B. Kurup and K.G. Prasad: *Hyp. Int.*, **4**, 622 (1978)
8. *Vogel's Textbook of Quantitative Chemical Analysis*, 5th Edn. ELBS, p.448 (1989)
9. C.C. Dey and B.K. Sinha: *Il Nuovo Cimento A*, (accepted for publication)
10. E. Matthias, W. Schneider and R.M. Steffen: *Phys. Lett.*, **4**, 41 (1963)