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III–12 The Electric Quadrupole Moment of the 2.083 MeV State of ^{140}Ce Derived from a TDPAC-Measurement

B. KLEMME and H. MIEMCZYK

Institut für Strahlen und Kernphysik, Bonn University, Germany

We studied the rotation of 329 keV–487 keV gamma-gamma angular correlation in the β^--decay of ^{140}La (see Fig. 1) in the crystalline electric field gradient of lanthanum-magnesium double-nitrate ($La_2(NO_3)_6Mg_3(NO_3)_6 \cdot 24\,H_2O$) by time differential measurement. A plot of the asymmetry ratio

$$R(t) = 2\frac{W(180°, t) - W(90°, t)}{W(180°, t) + W(90°, t)}$$

is shown in Fig. 2. The positive sign of $R(t)$ for $t \to 0$ is explained by a background of the prompt coincidences between the gamma lines of 487 keV and 1598 keV, since the anisotropy of a $4^+ - 2^+ - 0^+$ angular correlation is positive. Figure 2 exhibits the beginning of a very slow spin rotation. In order to derive the interaction frequency we fitted $R(t)$ by the theoretical spin rotation function for a static polycrystalline electric interaction in an axially symmetric field gradient.

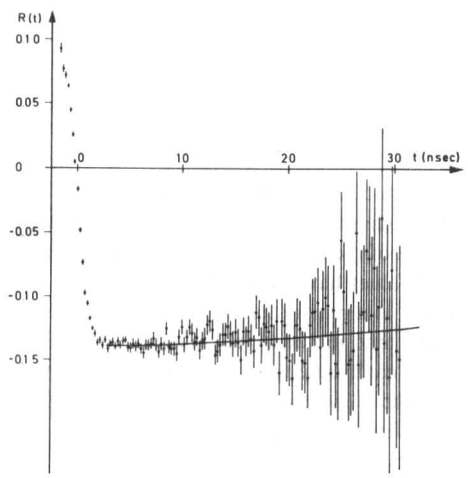

Fig. 2. Spin rotation observed in the 2083 keV 4^+-state of ^{140}Ce in an environment of lanthanum-magnesium double nitrate.

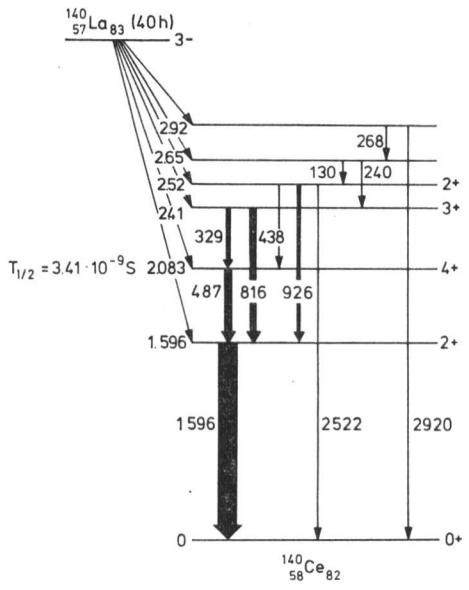

Fig. 1. Decay scheme of ^{140}La.

The result is

$$\omega_Q = \left|\frac{eQ_I\langle V_{zz}\rangle}{4I(2I-1)\hbar}\right| = 1.17_{15}\,\text{Mc/s}$$

The electric field gradient at the nuclear site of La in lanthanum-magnesium double-nitrate is derived from an NMR experiment with the stable nucleus ^{139}La in the same environment[1] by using for the quadrupole moment of the ground state of ^{139}La the value:[2]

$$Q_{7/2}(^{139}\text{La}) = +0.230_{10}\text{ b}$$

The cerium is produced by the β^--decay of ^{140}La primarily in the Ce^{4+} charge state and we assume[3] that it remains in this state (with an empty 4f-shell) for the time of observation of the spin rotation.

In the evaluation of the electric quadrupole moment of the 2.083 MeV state of ^{140}Ce we took into account the small difference between the Sternheimer correction factors γ_∞ of La^{3+} and Ce^{4+} [4] and obtained:

$$Q_{4^+}(^{140}\text{Ce}) = 0.404_{80}\text{ b.}$$

From the measured g-factor of the same state it was

concluded[3] that the 4^+ state of ^{140}Ce is predominantly the two-proton configuration (the neutron number is magic $N = 82$):

$$(g_{7/2}, d_{5/2})_{4^+},$$

whereas the ground state of ^{139}La which was used for the calibration is a $g_{7/2}$ single proton state (also with $N = 82$). We compared both quadrupole moments with the prediction of the shell model:

$$\begin{aligned} Q_I(g_{7/2})_{7/2^+} &= -0.6667\langle j_1|r_1^2|j_1\rangle \\ Q_I(g_{7/2}, d_{5/2})_{4^+} &= -0.2415\langle j_1|r_1^2|j_1\rangle \\ &\quad + 0.1203\langle j_2|r_2^2|j_2\rangle \\ &\approx -0.1212\langle j_1|r_1^2|j_1\rangle. \end{aligned}$$

The shell model predicts that the quadrupole moment of the single proton state is by a factor of five larger than that of the two particle state whereas the experimental values have about the same magnitude. We take this as a remarkable experimental indication for the fact that in the actual nuclear structure many particles contribute to the nuclear spin.

As the accuracy of our experimental result is limited by the very slow rotation, we looked for another environment which produces a larger electric field gradient at the nuclear site. In recent[5] TDPAC-measurements with antiferroelectric substances of the perovskit structure such a large electric field gradient was observed in $PbTiO_3$. We have therefore tried to use this lattice as an environment for the ^{140}La activity. Preliminary measurements gave indeed a faster spin rotation. The shape of $R(t)$ showed also that the interaction is static and not time-dependent.

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