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Spectroscopic quadrupole moments of high-spin isomers in ^{193}Pb

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Abstract. The quadrupole interaction of high-spin isomers in ^{193}Pb implanted into solid Hg cooled at a temperature $T = 170$ K has been investigated by the time-differential perturbed γ-ray angular-distribution method. Spectroscopic quadrupole moment values of $|Q_s| = 0.22(2)$ eb and 0.45(4) eb have been deduced for the $21/2^-$ and $33/2^+$ three-neutron states, respectively. A much higher value $|Q_s| = 2.84(26)$ eb has been determined for the $29/2^-$ isomer, the band head of a magnetic rotational band.

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The neutron-deficient Pb nuclei exhibit a rich variety of structures. Spherical states associated with the $Z = 82$ shell closure are coexisting at low energies with deformed states involving proton particle-hole intruder excitations across the closed shell. Particular interest has attracted the observation of regular bands with a rotational-like pattern involving sequences of enhanced magnetic dipole transitions which were interpreted as a novel rotational mode, the magnetic rotation [1]. The $M1$ bands in Pb isotopes are based on high-spin proton excitations into the $h_{9/2}$ and $i_{13/2}$ orbitals coupled to neutron-hole excitations in the $i_{13/2}$ shell with a perpendicular orientation of the orbitals near the band head. This coupling has been recently confirmed in the case of the $T_{1/2} = 9$ ns, $I^\pi = 29/2^-$ magnetic rotational band head in ^{193}Pb by the g-factor measurement [2]. Angular momentum in the bands is gained by the shears mechanism that involves a simultaneous re-orientation of the proton-particle and neutron-hole angular momenta into the direction of the total angular momentum [3].

Static quadrupole moments are known to provide direct fingerprints for nuclear shape coexistence. In the Pb nuclei these moments were systematically investigated for one- and two- neutron states [4] and their values are pointing to almost spherical shapes. Recently, the quadrupole moments of the 11^- isomers in ^{194,196}Pb, described by the proton intruder $(h_{9/2}i_{13/2})$ configuration, have been measured [5,6]. The derived values (*e.g.*, $|Q_s|(11^-, {}^{196}\mathrm{Pb}) = 3.41(66)$ eb) exceed by about an order of magnitude the values of the neutron states, indicating an increased collectivity [7]. In the present work we report on static quadrupole moment measurements for high-spin isomeric states in ^{193}Pb. The investigated states were the 9 ns $29/2^-$ magnetic rotational band head described by the $\nu(i_{13/2}^{-1}) \otimes \pi(h_{9/2}i_{13/2})_{11^-}$ configuration [2], as well as the 22 ns $21/2^-$ and 135 ns $33/2^+$ states involving three-neutron excitations [8].

The quadrupole interaction (QI) of the isomeric states in ^{193}Pb has been studied in the electric-field gradient (EFG) of the polycrystalline lattice of solid Hg by applying the pulsed-beam time-differential perturbed angular-distribution (TDPAD) method. The experiment has been carried out at the XTU-Tandem of Laboratori Nazionali di Legnaro. The states of interest were populated and aligned in the ^{170}Er(^{28}Si, 5n) reaction with a 143 MeV ^{28}Si beam having a pulse width of 1.5 ns at a repetition

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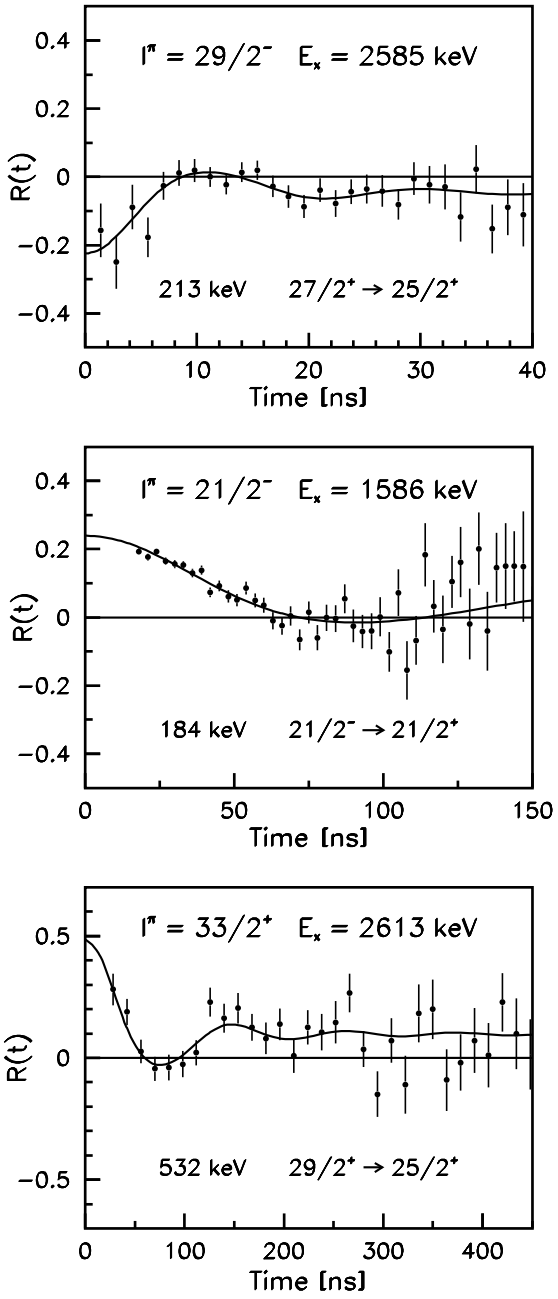

Fig. 1. Modulation patterns resulting from the quadrupole interaction of high-spin isomeric states of ^{193}Pb in solid Hg at a temperature of 170 K. The excitation energies of the isomers are relative to the energy of the $13/2^+$ long-lived isomer.

period of 800 ns. The excited ^{193}Pb nuclei recoiled out of the 0.5 mg/cm^2 ^{170}Er foil into a solid 0.2 mm Hg layer mounted on a Cu cold finger held at a temperature $T = 170$ K. Planar and large-volume Ge detectors were used for detecting the γ-rays. In off-line analysis of the list-mode stored data, background-subtracted time spectra gated by various γ-rays de-exciting the isomers were created for each detector. The quadrupole interaction results in a modulation pattern which is superimposed on the exponential decay of the γ-ray time spectra. Following the standard procedure in TDPAD experiments [9] the quadrupole modulation spectra are obtained from the normalized time spectra of the detectors placed at 0° and 90° with respect to the beam direction. The QI pattern depends on the spin and the quadrupole coupling constant $\nu_Q = Q_s V_{zz}/h$, where V_{zz} is the axially symmetric EFG strength. The quadrupole frequency decreases quadratically with the spin I and, for a half-integer spin, is given by $\omega_0 = 3\pi\nu_Q/I(2I-1)$. Due to the high spin value and short lifetime of the investigated isomers, in the present experiment it was not possible to evidence the full quadrupole period $T_0 = 2\pi/\omega_0$ and only the structure at the beginning of the modulation patterns could be observed. Examples of quadrupole interaction spectra corresponding to selected γ-rays are illustrated in fig. 1. The deduced values for the quadrupole coupling constant were 1203(90) MHz, 91(7) MHz and 191(14) MHz for the $29/2^-$, $21/2^-$ and $33/2^+$ states, respectively. With an EFG calibration of $V_{zz}(\mathrm{PbHg}) = 17.4(9) \times 10^{21}$ V/m^2 at $T = 170$ K, obtained by using data from ref. [10], absolute values of spectroscopic quadrupole moments for the high-spin isomers in ^{193}Pb have been derived as $|Q_s|(21/2^-) = 0.22(2)$ eb, $|Q_s|(33/2^+) = 0.45(4)$ eb and $|Q_s|(29/2^-) = 2.84(26)$ eb. Note that the small quadrupole moments determined for the $21/2^-$ and $33/2^+$ states are similar to the values reported for $13/2^+$ one-neutron and 12^+ two-neutron states in light Pb nuclei [4]. Rather spherical shapes are therefore inferred for the $21/2^-$ and $33/2^+$ isomeric states described by three-neutron configurations. A much larger $|Q_s|$ value was determined for the $29/2^-$ dipole band head which involves the coupling of the $(i^{-1}_{13/2})$ neutron state with the more deformed $(h_{9/2}i_{13/2})_{11^-}$ proton state. This is the first static quadrupole moment reported for a magnetic rotational band. The present results are thus providing evidence concerning shape coexistence for three-particle excitations in the neutron-deficient Pb region.

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