Rapid Communications

Nuclear isovector valence-shell excitation of ^{202}Hg

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(Received 20 October 2018; published 9 January 2019)

Excited states of ^{202}Hg have been studied via the ^{12}C(^{202}Hg, ^{202}Hg*) Coulomb excitation reaction at a beam energy of 890 MeV. The γ-ray transitions from the excited states of ^{202}Hg were detected by the Gammasphere array. The intensities of the observed γ rays determined the relative populations of the excited states which were used to extract the absolute $M1$ and $E2$ transition strength distributions for excited 2^+ states of ^{202}Hg up to 2 MeV. The measured absolute $B(M1; 2^+_7 \rightarrow 2^+_1)$ strength of $0.18(8)\mu_N^2$ indicates that the 2^+_7 level of ^{202}Hg is the main fragment of the proton-neutron mixed-symmetry $2^+_{1,\mathrm{ms}}$ state. Upper limits for the F-spin mixing matrix elements of ^{202,204}Hg are determined as well.

DOI: 10.1103/PhysRevC.99.011303

The emergence of nuclear collectivity from the effective nucleon-nucleon interactions represents one of the outstanding challenges in nuclear structure physics. One of these effective interactions is the attractive quadrupole-quadrupole interaction between valence protons and neutrons. It is known to be the reason for quadrupole collectivity in most heavy open-shell nuclei. It leads to a coherent mixing of collective quadrupole excitations of the proton and neutron subspaces and, thus, to low-energy nuclear states in which protons and neutrons collectively move in phase. This collective mode can successfully be described by geometrical models which consider the nucleus as a homogeneous object with a certain shape which can vibrate or rotate [1]. The main disadvantage of this approach is the complete loss of the fundamental many-body character of the nuclear system.

A theoretical approach to the modeling of quadrupole-collective heavy nuclei which provides an attempt to bridge the calculation of nuclear properties from fundamental nucleon-nucleon interactions to the collective model is the interacting boson model (IBM) [2]. Its sd-IBM-2 version [3,4], which describes the quadrupole-collective excitations in even-even nuclei, uses the approximation that valence nucleons are pairwise coupled to N_π proton or N_ν neutron monopole (s) or quadrupole (d) bosons. In a panoply of case studies, the IBM has been demonstrated [4] to successfully describe the main features of quadrupole-collective nuclear structures and the shape transitions between them as a function of valence nucleon numbers. The sd-IBM-2 yields quantum states that are characterized by a certain degree of coherence of proton-boson and neutron-boson contributions. This coherence is quantified by the F spin which is, for valence bosons, the analog to isospin for nucleons. The lowest-lying states are characterized by the F-spin quantum number $F = F_{\max} = (N_\pi + N_\nu)/2$, and their boson wave functions are completely symmetric under pairwise exchange of proton and neutron bosons.

Besides these full-symmetry states (FSSs), the sd-IBM-2 predicts, in addition, the existence of an entire class of states with wave functions that contain parts that are antisymmetric under the pairwise exchange of proton and neutron bosons [3]. These mixed-symmetry states (MSSs) are characterized by F-spin quantum numbers $F \leqslant F_{\max} - 1$. Their properties, such as excitation energy, electromagnetic decay, or F-spin purity, are sensitive to some parameters of the sd-IBM-2 space that are not accessible otherwise, such as the strength of the Majorana interaction, F-vector boson transition charges, or the size of the mixing matrix element between FSSs and MSSs.

According to the IBM-2, the lowest-lying isovector valence-shell excitation in vibrational nuclei is the one-quadrupole-phonon $2^+_{1,\mathrm{ms}}$ state [3,4]. The isovector character leads to unique decay properties of this $2^+_{1,\mathrm{ms}}$ state. The most indicative signature is a strong $M1$ transition to the fully symmetric one-quadrupole-phonon 2^+_1 state as well as a weakly collective $E2$ transition (≈ 1 W.u.) to the ground state [5–9]. This strong $M1$ matrix element ($|\langle 2^+_1||M1||2^+_{1,\mathrm{ms}}\rangle| \approx 1\mu_N$) [9], which is forbidden for isoscalar transitions [10], serves as the main experimental signature used for identification of one-phonon MSSs. A further signature is an enhanced $E1$ transition between the full-symmetry octupole state and the $2^+_{1,\mathrm{ms}}$ state in comparison to the 2^+_1 state [9]. This is due to the isovector nature of the $E1$ transition operator in the same manner as the isovector nature of the $M1$ transition operator enhances the $M1$ transition strengths between MSSs and FSSs [11].

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One-quadrupole-phonon MSSs were identified all across the nuclear chart; in the mass $A \approx 90$ region [6,12,13], in the mass $A \approx 130$ region [14–19] and, most recently, in the mass $A \approx 200$ region [20,21]. The experimental information accumulated up to now suggests that pronounced one-phonon MSSs can be expected when both protons and neutrons occupy orbitals with high angular momenta as in the case of ^{212}Po [20]. However, ^{204}Hg offers an opposite example–even though its valence structure is dominated by orbitals with small angular momenta for both protons and neutrons, ^{204}Hg exhibits a $2^+_{1,\mathrm{ms}}$ state with an even larger $M1$ decay strength than in ^{212}Po [20,21]. ^{202}Hg exhibits a similar valence structure as ^{204}Hg but with two additional neutron holes. Low-lying states of ^{202}Hg can be formed from excitations of the valence holes to the $\pi(2d_{3/2})^{-2}\,\nu(2f_{5/2})^{-2}(3p_{3/2})^{-2}$ orbitals. Its structure is dominated by orbitals with small angular momenta similar to the structure of ^{204}Hg. The extent to which a model space of several low-spin orbitals is capable of supporting F-spin symmetry is unknown as more bosons contribute to the wave functions.

This experiment aims to identify the $2^+_{1,\mathrm{ms}}$ state of ^{202}Hg and to determine how its properties change in comparison to the known $2^+_{1,\mathrm{ms}}$ states of isotopes in the vicinity of the doubly magic nucleus ^{208}Pb especially ^{204}Hg. Furthermore, it is intriguing to analyze and compare the evolution of F-spin mixing of $Z = 80$ isotopes to the one observed in $N = 80$ isotones. Hence, a projectile Coulomb-excitation measurement was carried out to populate 2^+ states and to search for the one-quadrupole-phonon MSS of ^{202}Hg.

The experiment was performed with a beam of stable ^{202}Hg ions at the ATLAS facility at Argonne National Laboratory (ANL). The pulsed (12-MHz) beam was accelerated up to 890 MeV and impinged on a 1 mg/cm^2-thick $^{\mathrm{nat}}$C target. The target chamber was surrounded by Gammasphere [22], which for this experiment was composed of 100 high-purity germanium (HPGe) detectors arranged in 16 rings. Data were recorded when one γ ray was detected in any HPGe detector. The chosen beam energy is equivalent to $\approx$85% of the Coulomb barrier for the ^{202}Hg + ^{12}C reaction. A total of 8.4×10^8 events of γ-ray-fold $\geqslant 1$ was collected over a period of 20 h. To suppress the background, the "beam-off" (with respect to the accelerator radio frequency) spectrum was subtracted from the "beam-on" spectrum, appropriately scaled to minimize the 1461-keV ^{40}K room background transition. The Doppler-corrected background-subtracted singles spectrum of this high statistics measurement is dominated by the 439-keV $2^+_1 \to 0^+_1$ transition in ^{202}Hg, with 2.5×10^8 events [see Fig. 1(a)]. About 2% of the data consists of γ-ray coincidence events of fold 2 or higher and was sorted in an E_γ-E_γ matrix. A spectrum of γ rays in coincidence with the $2^+_1 \to 0^+_1$ transition is provided in Fig. 1(b). In the present experiment, 39 peaks have been observed which can be firmly assigned to transitions between excited levels of ^{202}Hg [23–33]. The resulting level scheme is shown in Fig. 2. Spin and parity quantum numbers were adopted from Ref. [34]. In the present reaction, eight 2^+ states of ^{202}Hg were populated. The lowest-lying 2^+ level at 439 keV is the fully symmetric one-quadrupole-phonon excitation. Concerning the assignment of the $2^+_{1,\mathrm{ms}}$ state with the decay signature described above, the 2^+ level at 1794 keV appears to be the most promising candidate as the main fragment. In the region of $\approx$2-MeV excitation where the $2^+_{1,\mathrm{ms}}$ level is expected, it is the state populated with the highest intensity. It decays predominantly via the 1354-keV transition to the 2^+_1 state with an additional small branch to the 2^+_2 state via the 833-keV γ ray. The 2^+ state at 1823 keV exhibits a similar decay pattern and appears to be a small fragment of the $2^+_{1,\mathrm{ms}}$ state. The intensity of its strongest decay, via the 1384-keV transition, to the 2^+_1 state is only one-fifth that of the 1354-keV transition of the 1794-keV level. Negative-parity states of ^{202}Hg have also been populated in the present measurement. Three 3^- levels were observed at 2357, 2709, and 3166 keV with the largest feeding reaching the second state. Besides the 3^- states, one further negative-parity state, a 5^- state at 1966 keV, was populated. In addition to the 2^+ and negative-parity levels, two 4^+ states were observed at 1120 and 1312 keV, two 0^+ levels at 1564 and 1643 keV, as well as a single 6^+ level at 1989 keV. Finally, it is worth noting that six additional levels with unknown spin and parity quantum numbers are also present in our data with respective energies of 1348, 2134, 2293, 2456, 2516, and 2681 keV. Only the 2681-keV state has not been observed in earlier work [34]. Table I reports on the properties of the levels seen in the present Rapid Communication.

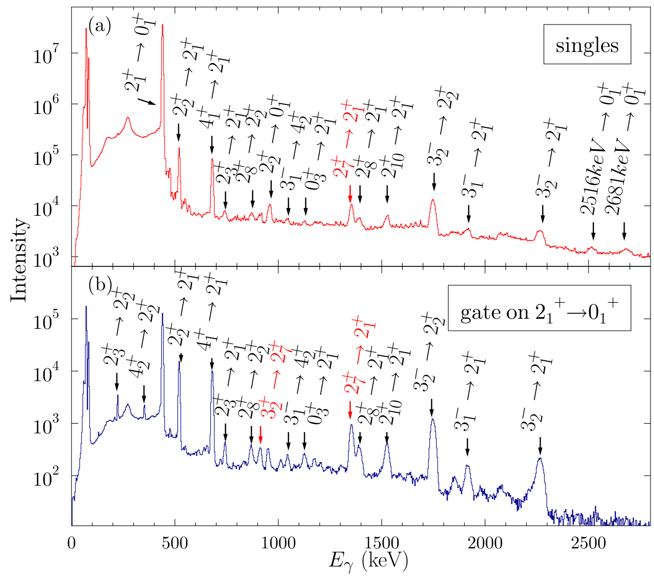

FIG. 1. Doppler-corrected time-background-subtracted γ-ray spectra after projectile Coulomb excitation on a $^{\mathrm{nat}}$C target; (a) singles spectrum; (b) spectrum of γ rays in coincidence with the $2^+_1 \to 0^+_1$ transition. In both spectra the transitions relevant for this Rapid Communication are highlighted.

The Coulomb-excitation yields for the populated ^{202}Hg levels are determined through the intensities of the observed γ rays, complemented with known branching ratios, and calculated electron-conversion coefficients [35]. The yields of excited levels relative to that of the 2^+_1 state measure their Coulomb-excitation cross section relative to the 2^+_1 state. The experimental relative yields were fitted to the Winther–de Boer theory [36] using the multiple Coulomb-excitation code

TABLE I. Measured properties of the levels and γ-ray transitions in ^{202}Hg. Level energies and spin assignments are adopted from Ref. [34] unless otherwise noted. The relative γ-ray intensities are corrected for efficiency.

E_{Level} (keV)	J^π	E_γ (keV)	J_f^π	I_γ	A_2/A_0	A_4/A_0	δ	$E\lambda$	$B(E\lambda)\downarrow$[ab]	$B(M1)\downarrow$[b]	$B(E\lambda)_{\text{lit}}$[bc]
439	2_1^+	439	0_1^+	$1.00(1)\times10^6$	0.012(7)	0.002(11)		$E2$			17.35(14) [27,38]
960	2_2^+	960	0_1^+	620(13)				$E2$	0.039(3)		0.087(21) [27,28]
		520	2_1^+	4444(44)	0.11(1)	0.012(16)	0.9(1)[40]	$E2$	2.7(3)	$43(8)\times10^{-4}$	5.6(15)[40]
1120	4_1^+	680	2_1^+	4008(41)	0.16(2)	−0.01(3)		$E2$	26.6(5)		26.5(8) [27,28]
1182	2_3^+	1182	0_1^+	<50[d]				$E2$	<0.015		
		743	2_1^+	183(4)	0.21(4)	−0.039(54)	2.1(4)	$E2$	$0.54^{+0.09}_{-0.47}$	$33^{+5}_{-29}\times10^{-5}$	
		222	2_2^+	356(15)	0.12(2)	−0.007(22)	−0.13(3)	$E2$	9^{+5}_{-8}	$0.13^{+0.07}_{-0.12}$	
1312	4_2^+	872	2_1^+	113(13)				$E2$	0.74(6)		
		352	2_2^+	221(9)				$E2$	137(17)		
		129	2_3^+	38(17)				$E2$	3413(1216)		
1348	(2^+)[e]	908	2_1^+	73(7)				$E2$	1.52(4)		
1390	2_4^+	1390	0_1^+	15(6)[d]				$E2$	0.013(1)		
		950	2_1^+	136(6)				$E2$	<1	$<6\times10^{-3}$	
		429	2_2^+	39(4)				$E2$	12(4)		
		207	2_3^+	20(5)				$E2$	234(96)		
1564	0_3^+	1125	2_1^+	114(6)				$E2$	5.8(2)		
1575	2_5^+	1136	2_1^+	15(5)[d]				$E2$	0.47(2)		
		615	2_2^+	26(3)				$E2$	17(6)		
1643	0_4^+	1204	2_1^+	44(6)				$E2$	2.6(1)		
1794	2_7^+	1794	0_1^+	30(14)[d]				$E2$	0.13(6)		
		1354	2_1^+	1086(17)	0.23 (2)	0.028(25)	0.06(4)	$E2$	0.1(1)	0.18(8)	
		833[f]	2_2^+	33(7)				$E2$	6(3)		
1823	2_8^+	1823	0_1^+	18(7)[d]				$E2$	0.052(3)		
		1384	2_1^+	221(13)				$E2$	<4	<0.027	
		864	2_2^+	91(7)				$E2$	11(4)		
		641	2_3^+	37(3)				$E2$	19(7)		
1966	5_1^-	654	4_2^+	78(5)				$E1$			
1966	2_{10}^+	1527	2_1^+	171(30)				$E2$	10.0(3)		
		655	4_2^+	14(3)				$E2$	55(22)		
1989	6_1^+	868	4_1^+	21(2)				$E2$	24.9(1)		25 [28]
2134	(2^+)[e]	1014	4_1^+	94(6)				$E2$			
2293	(3,4)[g]	1853	2_1^+	117(8)				$E2$	3.40(5)		
2357	3_1^-	2357	0_1^+					$E3$	2.5(1)		
		1917	2_1^+	328(13)				$E1$			
		1396	2_2^+	247(16)				$E1$			
		1174[f]	2_5^+	100(8)				$E1$			
		1045[f]	4_2^+	100(9)				$E1$			
2456	(2^+)[e]	1495[f]	2_2^+	42(15)				$E2$			
2516	(1,2)[e]	2516	0_1^+	181(11)				$E2$	0.11(1)		
2681[f]	(2^+)[e]	2681[f]	0_1^+	226(14)				$E2$	0.20(2)		
2709	3_2^-	2709	0_1^+					$E3$	21(1)		<25[29]
		2264[f]	2_1^+	611(23)				$E1$			
		1747[f]	2_2^+	2431(51)	−0.17(2)	0.04(3)		$E1$			
		1524[f]	2_3^+	373(29)				$E1$			
		914[f]	2_7^+	122(14)				$E1$			
3166	3_3^-	3166	0_1^+					$E3$	1.0(1)		
		1980[f]	2_1^+	74(36)				$E1$			

[a]Extracted via Coulomb-excitation analysis in the present experiment.
[b]$B(M1)$ values are given in μ_N^2, $B(E2)$, $B(E3)$, and $B(E4)$ values are given in Weisskopf units [1 W.u. $(E1) = 2.22\ e^2\text{fm}^2$, 1 W.u. $(E2) = 70.4\ e^2\text{fm}^4$, 1 W.u. $(E3) = 2.42\times10^3\ e^2\text{fm}^6$].
[c]The values in this column are the ones given in Ref. [34], converted to single-particle units.
[d]Calculated via literature branching ratio [34].
[e]Assumed 2^+ state in the analysis.
[f]Newly observed.
[g]Assumed 4^+ state in the analysis.

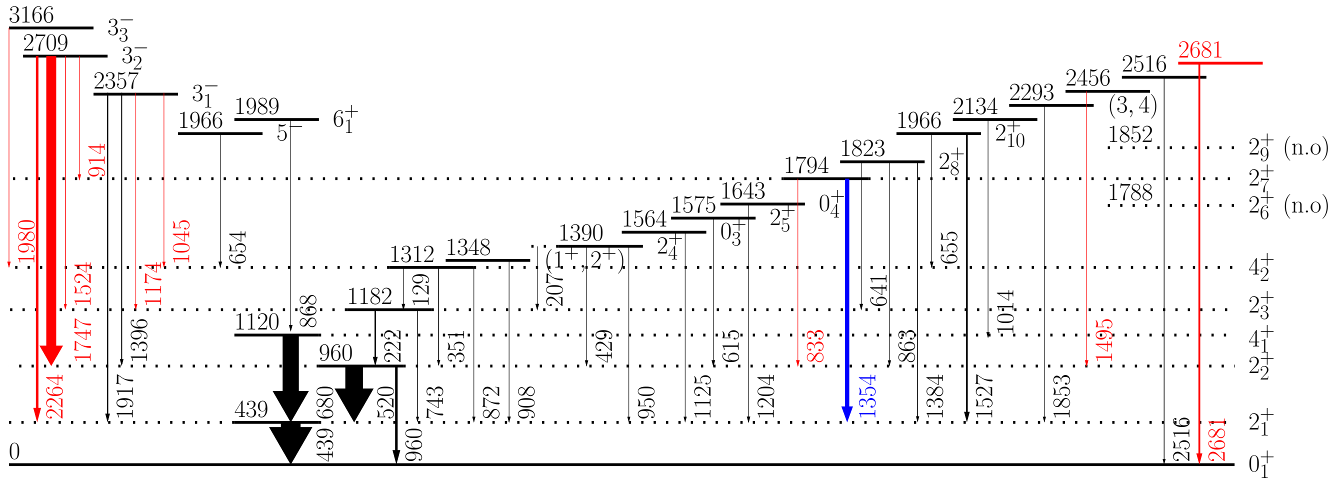

FIG. 2. Experimental level scheme of ^{202}Hg from this Rapid Communication. The thickness of the arrows corresponds to the intensities measured in the present Rapid Communication. The $2_1^+ \rightarrow 0^+$ transition intensity is scaled down to fit into the figure. Newly observed transitions and levels are highlighted (red). The transition $2_7^+ \rightarrow 2_1^+$ is also highlighted (blue) as the 2_7^+ state is proposed to correspond to the dominant fragment of the $2_{1,\mathrm{ms}}^+$ state.

CLX [37], whereas taking the energy loss of the beam in the target into account. Absolute cross sections were derived using the previously measured values for the reduced transition probability, i.e., $B(E2; 2_1^+ \rightarrow 0_1^+) = 17.35(14)$ W.u. [27,38] and the quadrupole moment $Q(2_1^+) = 1.01(13)\, e^2\mathrm{b}^2$ [38], providing an unambiguous set of transition matrix elements for one-step excitation. This information in combination with the experimental branching and multipole mixing ratios can be used to obtain the $E2$ and $M1$ strength distributions for the deexcitation of the excited 2^+ states. The 4π coverage and the resulting high detection efficiency of Gammasphere enable measurements of angular distributions (cf. Fig. 3) for sufficiently intense transitions. This allows for extracting the A_2/A_0 and A_4/A_0 coefficients given in Table I. A good example for a γ ray with pronounced anisotropy is the $3_2^- \rightarrow 2_2^+$ transition at 1747 keV with its clear dipole character. States with lifetimes of a few tens of picoseconds show flat or attenuated distributions due to the recoil in vacuum effect [39]. This effect causes the isotropy of the $2_1^+ \rightarrow 0_1^+$ [$\tau(2_1^+) = 39.3(3)$ ps] transition and the attenuation of the angular distribution of the $4_1^+ \rightarrow 2_1^+$ [$\tau(4_1^+) = 3.0(1)$ ps] and $2_2^+ \rightarrow 2_1^+$ [$\tau(2_2^+) = 20(4)$ ps] ones. For the $2_3^+ \rightarrow 2_2^+$, $2_3^+ \rightarrow 2_1^+$, and $2_7^+ \rightarrow 2_1^+$ transitions, the extracted angular distribution coefficients are presented in Table I. Wherever possible, the measured angular distributions agree with the previously adopted spin-parity assignments found in Ref. [34]. The multipole mixing ratios of $2^+ \rightarrow 2_1^+$ transitions were worked out with an iterative procedure. The technique is described in Ref. [21] and is based on fitting, with the Coulomb-excitation code GOSIA [41], transition matrix elements for a subset of states to Coulomb cross sections; e.g., the 2^+ level of interest, the most populated 3^- state, the 2_1^+ level, and the ground state. The only free parameter in this procedure is the $E2/M1$ multipole mixing ratio of the $2^+ \rightarrow 2_1^+$ transition being considered. The outcome of this method is a decisively small multipole mixing ratio $\delta = 0.06(4)$ for the $2_7^+ \rightarrow 2_1^+$ transition (cf. Table I and Fig. 3), which indicates its predominant $M1$ character making the assignment of δ from the angular distribution [cf. Fig. 3(d)] unique.

This experiment was performed to determine $M1$ strengths of $2^+ \rightarrow 2_1^+$ transitions in order to identify the $2_{1,\mathrm{ms}}^+$ state of ^{202}Hg. For the 2_7^+ state at 1794 keV, a transition strength of $B(M1; 2_7^+ \rightarrow 2_1^+) = 0.18(8)\mu_N^2$ was measured, a value significantly larger than the $10^{-2}\mu_N^2$ one typically observes between FSSs [9]. This should be viewed as a strong indication that the 2_7^+ level is of mixed-symmetric nature. For the close-lying 2_8^+ state, an upper limit $B(M1; 2_8^+ \rightarrow 2_1^+) < 0.027\mu_N^2$, could be extracted. This maximum applies to the extreme as-

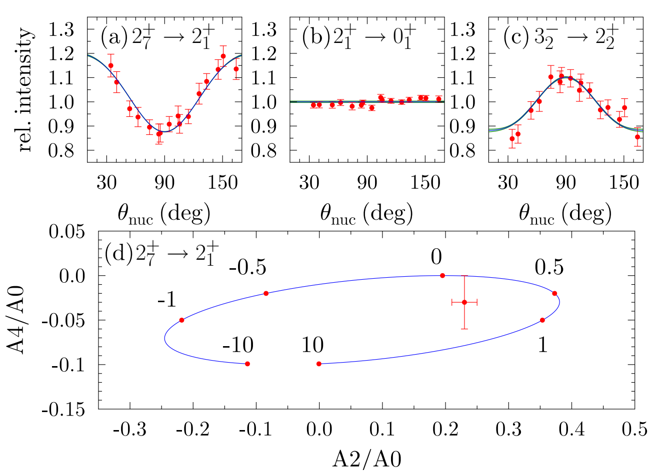

FIG. 3. Angular distributions measured for the (a) 1354-, (b) 439-, and (c) 1747-keV transitions. The solid line are fits in (a) and (c) to a sum of Legendre polynomials and in (b) to a constant. The resulting A_2/A_0 and A_4/A_0 coefficients of the 1354-keV transition are compared to (d) an angular distribution ellipse calculated with the statistical tensor for the 2_7^+ state. The numbers on the ellipse denote the multipole mixing ratio δ for the $2_7^+ \rightarrow 2_1^+$ transition.

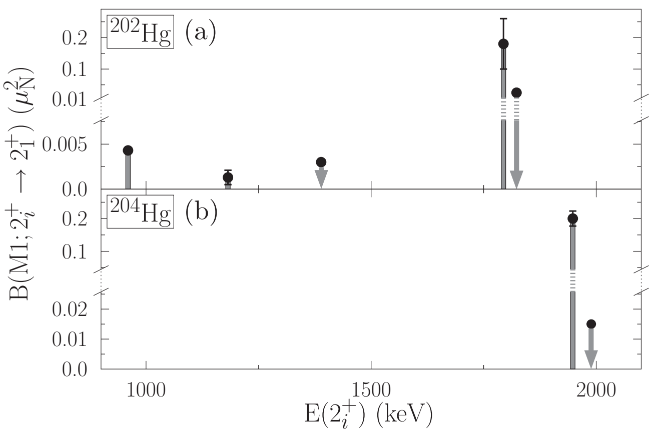

FIG. 4. $M1$ strength distributions $B(M1; 2^+_i \rightarrow 2^+_1)$ of (a) ^{202}Hg and (b) ^{204}Hg. Upper limits are illustrated as arrow heads. The y axes are divided into two parts with different scales.

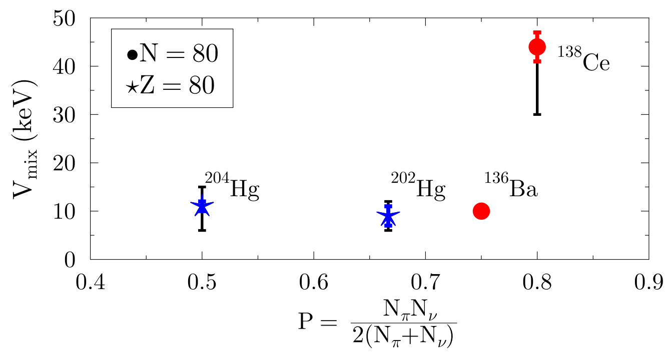

FIG. 5. F-spin mixing matrix elements V_{mix} of $N = 80$ isotones and $Z = 80$ isotopes as a function of P with statistical (color) and systematical error (black).

sumption of a pure $M1$ character for the $2^+_8 \rightarrow 2^+_1$ transition. The $M1$ strength distribution (cf. Fig. 4) supports the notion that the 2^+_7 level at 1794 keV is the main fragment of the $2^+_{1,\mathrm{ms}}$ state of ^{202}Hg and that the 2^+_8 state represents at most a small fragment of it. The weakly collective ($\sim$0.1 W.u.) $E2$ decay of the 2^+_7 level to the ground state is in line with the expected decay behavior of a MSS. The 3^-_2 state at 2709 keV is the most strongly populated negative-parity excitation observed. The measured branching ratio of the γ decays of the 3^-_2 state allows for determining the $E1$ ratio [42] $R_{E1} = \frac{B(E1;3^-_2\rightarrow 2^+_7)}{B(E1;3^-_2\rightarrow 2^+_1)} \approx 3$. The enhancement of the $E1$ transition to the 2^+_7 state in comparison to the 2^+_1 state is another indication of the mixed-symmetric nature of the 2^+_7 state, provided that the 3^-_2 state is understood as the dominant fragment of the isoscalar octupole vibration of ^{202}Hg. Analogous $E1$-decay behaviors of fully symmetric octupole excitations were observed in the case of ^{204}Hg [21] and of ^{92}Zr and ^{94}Mo [42]. ^{202}Hg exhibits an nearly unmixed, isolated $2^+_{1,\mathrm{ms}}$ state as was also observed earlier for ^{204}Hg [21] and ^{212}Po [20] in the vicinity of the doubly magic nucleus ^{208}Pb. The $B(M1; 2^+_i \rightarrow 2^+_1)$ strength distributions observed in ^{202,204}Hg are compared in Fig. 4. In both Hg isotopes, a 2^+ level lies within an energy range of 50 keV of the dominant $2^+_{1,\mathrm{ms}}$ fragment (cf. Fig. 4). It carries a small fraction of the total $M1$ strength to the 2^+_1 state. The upper limits for this $M1$ strength are $0.027\mu^2_N$ in ^{202}Hg and $0.018\mu^2_N$ in ^{204}Hg, respectively. For the quantification of the fragmentation of the $2^+_{1,\mathrm{ms}}$ states of ^{202,204}Hg, one determines the F-spin mixing matrix element V_{mix} in a two-state mixing scenario between the $2^+_{1,\mathrm{ms}}$ state and a close-lying 2^+ FSS [14]. Here, the $M1$ strength between FSSs has to be considered and is estimated as $B(M1; 2^+_2 \rightarrow 2^+_1) = 0.0043(8)\mu^2_N$ for ^{202}Hg and is applied to ^{204}Hg. Upper limits of the F-spin mixing matrix elements in Hg isotopes can then be determined: $V_{\mathrm{mix}}(^{202}\mathrm{Hg}) < 9(2)^{+3}_{-3}$ keV and $V_{\mathrm{mix}}(^{204}\mathrm{Hg}) < 11(1)^{+4}_{-5}$ keV. The F-spin mixing matrix elements determined for the $Z = 80$ isotopes are plotted in Fig. 5 as a function of the P factor [43] and compared to the literature values for the $N = 80$ isotones [14,44]. The low F-spin mixing of $Z = 80$ isotopes and the $N = 80$ isotone ^{136}Ba $V_{\mathrm{mix}}(^{136}\mathrm{Ba}) < 10$ keV [14] demonstrates the preservation of the F-spin quantum number in the vicinity of shell closures in heavy nuclei and highlights the more strongly broken F-spin symmetry observed in ^{138}Ce $V_{\mathrm{mix}}(^{138}\mathrm{Ce}) = 44(3)^{+3}_{-14}$ keV [14].

In conclusion, a projectile Coulomb-excitation experiment was performed to identify the $2^+_{1,\mathrm{ms}}$ state of ^{202}Hg. In total, 39 transitions from excited states of ^{202}Hg, ten previously unknown, were observed and their branching ratios determined. These 39 transitions are assigned to 24 excited states, including a previously unknown one at 2681 keV. Information on 40 electromagnetic transition rates was deduced. In particular, the decay properties of the 2^+_7 state at 1794 keV were determined. Its comparatively large $M1$ strength justifies its assignment as the main fragment of the $2^+_{1,\mathrm{ms}}$ state of ^{202}Hg. This assumption is supported further by the measured absolute $E2$ transition strengths to the ground state and to the 2^+_1 state as well as by the R_{E1} ratio. Upper limits for F-spin mixing matrix elements V_{mix} in ^{202,204}Hg were determined. These indicate that F spin is a well-conserved quantum number in these $Z = 80$ isotopes.

G.R. acknowledges support from the Alexander von Humboldt foundation. N.P. and V.W. are supported by the DFG under Grant No. SFB 1245. This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357 and Grants No. DE-FG02-97ER41041(UNC) and No. DE-FG02-97ER41033(TUNL). This research used resources of ANL's ATLAS facility, which is a DOE Office of Science User Facility. This work was supported by BgNSF Grant No. DN08/23, and by the BMBF Grants No. 05P15(/18)RDFN1 and No. 05P15(/18)RDCIA.

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