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Core-Excited High-Spin Isomers in ^{212}Rn

D. Horn, O. Häusser, T. Faestermann, A. B. McDonald, T. K. Alexander, and J. R. Beene[(a)]
Atomic Energy of Canada Limited, Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada K0J 1J0

and

C. J. Herrlander
Research Institute of Physics, S-10405 Stockholm, Sweden
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We have observed isomeric states in ^{212}Rn with very high angular momenta (up to $J^\pi = 30^+$). The four isomers of highest spin contain core-excited neutron configurations, the spins of which are strongly aligned with those of the valence protons. The isomerism appears to result from a lowering of the excitation energies by 1 to 2 MeV compared to a sum of the unperturbed values for the constituent configurations.

Recently, mechanisms for producing isomers with very high spins (yrast traps) have been discussed. When such isomers exist, they are particularly useful in the study of nuclear structure at high angular momentum. These isomers might be caused by minima in shell-correction terms[1] overcoming the steeply rising liquid-drop energy, and may involve either triaxial or oblate equilibrium shapes. Additional effects would arise from the large residual interaction between states near the Fermi surface with maximum overlap of the nucleonic wave functions by alignment (MONA) of single-particle angular momenta.[2] Such isomers are expected to be oblate.

In the present work, we have found nine isomeric states in ^{212}Rn, and of those, the higher-lying levels appear to be of MONA origin. The experiments were carried out with the Chalk River Model MP tandem accelerator, and the results are summarized in Fig. 1. The five lower-lying isomers up to $J^\pi = 17^-$ are accounted for[3] by configurations of the four valence protons in ^{212}Rn, but above 6 MeV of excitation, the most appropriate model to explain the isomers appears to be coupling of valence protons to excited states of the ^{208}Pb core. Since the Pauli principle would inhibit excitation of core protons into valence orbitals at spins already occupied by valence protons, it is suggested that mainly the neutron part of the ^{208}Pb excited states contribute to the coupling. We shall discuss the experiments leading to the level assignments, including the magnetic-moment measurements with which we compare the calculated moments for our proposed configurations. Conclusions about core-coupled isomers may be drawn from the proposed configurations.

The heavy-ion reaction ^{204}Hg(^{13}C, $5n$) at $E(^{13}$C$) = 72$–85 MeV was used to produce ^{212}Rn at high angular momentum. The lifetimes of the isomeric levels and their sequence in ^{212}Rn were established by standard pulsed-beam techniques.[4] The data obtained include excitation functions of delayed and prompt γ rays, time distributions of delayed γ rays, and extensive γ-γ coincidence measurements. We have also determined concurrently angular distributions and linear polarizations of delayed γ rays. A Compton polarimeter consisting of three Ge(Li) detectors similar to the one described by Butler *et al.*[5] was used for the polarization measurements. A simultaneous fit of the angular distribution coefficients, A_2 and A_4, and of the linear polarization, P_γ, uniquely determined the angular momentum change, ΔJ, the multipolarity, λ, and the electric or magnetic character of each transition, as well as the mixing ratio, δ, though only the 1047-keV ($18^- \to 17^-$) transition was significantly mixed: $\delta(\langle E2\rangle/\langle M1\rangle)$

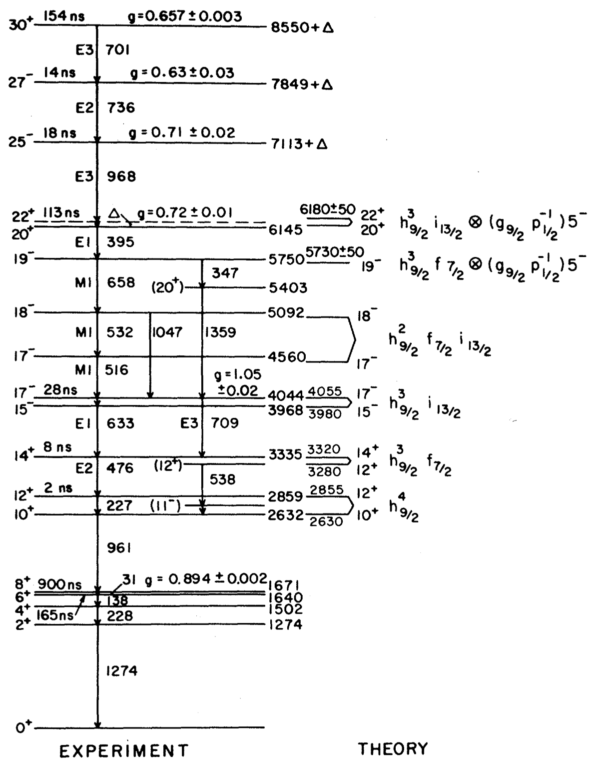

FIG. 1. Proposed ^{212}Rn level scheme including half-lives of isomeric states, transition multipolarities, and E or M character from angular distributions and polarization measurements, and observed g factors. Energies are given in keV. The unobserved transition $\Delta = E_x(22^+) - E_x(20^+)$ is discussed in the text. Theoretical predictions are from Ref. 3.

$=1.4$. This led to the level scheme and J^π assignments shown in Fig. 1. Note that the unobserved transition $\Delta = E_x(22^+) - E_x(20^+)$ was postulated because of prompt components in all the observed γ rays de-exciting the 22^+ isomer ($T_{1/2} = 113$ ns). The $E2$ assignment to this unobserved transition is the only link which is not based on experimental evidence in the sequence leading to 30^+ for the uppermost isomer. It does, however, agree with the theoretical prediction[3] for a 20^+, 22^+ doublet at this energy. To corroborate further the configuration assignments shown in Fig. 1 we have measured magnetic moments of the isomeric states using the time-differential perturbed angular correlation method (TDPAC) described in Ref. 4. The results are shown in Table I and also in Fig. 1. Additional support for the configurations comes from measured lifetimes for $E2$ transitions ($17^- \to 15^-$, $14^+ \to 12^+$, and $12^+ \to 10^+$) which agree within 30% with $B(E2)$ values calculated using an effective charge of 1.8.

As may be seen in Fig. 1, the agreement of theoretical and experimental level energies is very good up to the $J^\pi = 22^+$ state. Note that the $\pi(h_{9/2}{}^3 i_{13/2})$ and $\pi(h_{9/2}{}^3 f_{7/2})$ configurations for the 17^- to 14^+ sequence recur in the proposed 22^+ to 19^- sequence, this time coupled to the 5^- state of the ^{208}Pb core.[3] The measured g factor for the $J^\pi = 17^-$ state is in excellent agreement with that calculated[6] for an $(h_{9/2}{}^3 i_{13/2})$ proton state. The rather small g factors measured for isomers with $J \geq 22$ can be explained if neutron core excitations supply a significant fraction of the observed angular momentum. If, for the $J^\pi = 22^+$ isomer, one considers coupling with the 5^- core-excited state of ^{208}Pb, the calculated g factor is 0.80, while inclusion of only the $(p_{1/2}{}^{-1} g_{9/2})$ neutron component reduces the calculated value to 0.76. The observed g factor (0.72 ± 0.01) is even lower, suggesting that the 22^+ isomer is not a simple state.

Based on the g-factor measurements, other en-

TABLE I. Core-excited isomers in ^{212}Rn. The suggested configurations are proposals that agree with observed g factors and require the smallest attractive interaction to reach the observed ^{212}Rn excitation energy. See text.

J^π	Valence protons	Core excitation (neutrons)	Required attraction (MeV)	g factor calculated[a]	g factor[b] observed
30^+	$(h_{9/2}{}^2 i_{13/2}{}^2)20^+$	$(g_{9/2} i_{13/2}{}^{-1})11^+$ or	(-1.9)	0.65	0.657 ± 0.003
		$(k_{15/2} f_{5/2}{}^{-1})10^+$	(-2.2)	0.72	
27^-	$(h_{9/2}{}^3 i_{13/2})17^-$	$(g_{9/2} i_{13/2}{}^{-1})11^+$ or	-1.2	0.57	0.63 ± 0.03
		$(k_{15/2} f_{5/2}{}^{-1})10^+$	-1.6	0.64	
25^-	$(h_{9/2}{}^3 i_{13/2})17^-$	$(k_{15/2} p_{1/2}{}^{-1})8^+$	-1.6	0.68	0.71 ± 0.02
22^+	$(h_{9/2}{}^3 i_{13/2})17^-$	$(g_{9/2} p_{1/2}{}^{-1})5^-$	-1.1	0.76	0.72 ± 0.01

[a]Ref. 6.

[b]Corrected for Knight shift $(0.05 \pm 0.2)\%$ and diamagnetic shift (1.91%).

ergetically favored configurations are suggested in Table I for the higher-lying isomers. $B(E3)$ values estimated from experimental single-particle strengths[7] for the proposed configurations are within 10% of the values extracted from our data, except in the case of the 30^+ state, for which estimates are a factor of 5 too low. As indicated in Table I (column 3), the proposed configurations have excitation energies lower by 1–2 MeV than the sum of observed level energies of the valence protons and the unperturbed energies of the core-excited neutrons. It should be emphasized that the relevant core-excited states in ^{208}Pb are not expected to be isomeric and that attraction by the MONA mechanism—in the present cases the strongly attractive proton-neutron and proton–neutron-hole interaction for highly aligned orbitals[2,8,9]—is essential to produce the isomerism. Isomers of similar nature, but at lower angular momenta, have been found in ^{212}Po(18^+),[10] ^{206}Tl(12^-),[11] and ^{209}Bi($\frac{19}{2}^+$).[12] One might also speculate that such isomers with $J > 30$ exist in nuclei with neutron number $N > 126$. The high-spin isomers in ^{212}Rn are expected to have an oblate deformation, yet should not have rotational bands built on them—predictions that might be verified experimentally.

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[a]Present address: Oak Ridge National Laboratory, Oak Ridge, Tenn. 37830.

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