PHYSICAL REVIEW C VOLUME 48, NUMBER 5 NOVEMBER 1993

Near yrast states in doubly odd ^{214}Fr

M. E. Debray, A. J. Kreiner, J. M. Kesque,
M. Ozafran, A. Romo, H. Somacal, and M. E. Vazquez
Departamento de Física, Comisión Nacional de Energía Atómica, Buenos Aires, Argentina

J. Davidson and M. Davidson
*Departamento de Física, Facultad de Ciencias Exactas y Naturales,
Universidad de Buenos Aires, Buenos Aires, Argentina*

K. Ahn,* D. B. Fossan, Y. Liang, R. Ma, E.S. Paul, W. F. Piel, Jr., and N. Xu
Physics Department, State University of New York at Stony Brook, Stony Brook, New York 11794

(Received 11 March 1993)

High spin states of doubly odd ^{214}Fr$_{127}$ have been investigated using in-beam γ-ray and conversion electron spectroscopy techniques through the ^{206}Pb(^{11}B,3n) and ^{208}Pb(^{11}B, 5n) fusion-evaporation reactions. Completely new spectroscopic information has been obtained. The yrast level structure is established up to spin (19^+) and some information on γ transitions from higher-lying levels is also obtained. Two new isomers $T_{1/2} = 174(20)$ ns and $T_{1/2} = 11(2)$ ns were found. Configuration assignments for the low-lying levels are discussed. Information on residual proton-neutron interactions is extracted.

PACS number(s): 21.10.Hw, 21.10.Re, 23.20.Lv, 27.80.+w

I. INTRODUCTION

The region of the nuclear chart between the double closed shell nucleus ^{208}Pb and the well-deformed actinides is rich in structural changes. In particular, in the last decade, this region has become the object of numerous studies related to the discovery of very low-lying negative-parity collective states indicating the presence of an octupole instability and eventually stable octupole deformation. Most of the available experimental information, however, refers to even-even and odd-mass nuclei [1–12]. Comparatively little is known from in-beam studies on doubly-odd isotopes in this region [13–16]. A microscopic understanding of the development of collectivity will probably demand a better knowledge of residual proton-neutron (p-n) interactions which is contained in the evolution of the p-n $(j_\pi \otimes j_\nu)_{J^\pi}$ multiplets. The present study of ^{214}Fr is carried out as a contribution in that framework.

Prior to this study no γ transitions were known in ^{214}Fr. The only previous information was the existence of two isomeric α-emitting states [17], namely, $I^\pi = (1^-)$ of $T_{1/2} = 5$ ms and $I^\pi = (9^-)$ of $T_{1/2} = 3.4$ ms. So far the excited (9^-) state in ^{214}Fr was proposed exclusively on the basis of energy differences of α-particle groups stemming from this excited state and decaying into ^{210}At (Ref. [18]). Results of a contemporary study of ^{214}Fr by Byrne *et al.* [19] indicate an 8^- state, 45 keV below the 9^-, with a half-life of 4.9 ms, and the (1^-) as the two lowest-lying α-decaying states along with a rather complete level scheme very similar to the one presented in this paper.

The major difference between the two schemes is the relative ordering of the 143.2-299.2 keV and 312.7 - 118.7 keV transitions. There is a clear support for our placement in the first case, due to the existence of a 607.0 keV line, which is observed in the γ-γ coincidence spectra when gating on the 299.2, 312.7, and 471.8 keV transitions. The order of the 312.7-118.7 keV transitions is strongly supported by the intensity balance in the coincidence data. The $E1$ character of the 312.7 keV line follows from the conversion electron measurements. A coincidence intensity balance in spectra gated on transitions above the (17^+) state indicates an $M1$ character for the 118.7 keV line, while the ordering shown in Fig. 2 arises from balance in spectra gated on transitions below the (15^-) state.

Finally, the level scheme presented by Byrne *et al.* [19], reaches higher spin states being more complete above the (17^+) state, possibly due to the different reactions used in the two γ-γ coincidence experiments.

Here we report on the low and medium spin structures of ^{214}Fr where two isomers have been observed. Preliminary results of this work were reported earlier [20].

II. MEASUREMENTS AND RESULTS

Our measurements comprise gamma-ray excitation functions (in the 64–80 MeV energy range) and conversion electron spectra using the ^{208}Pb(^{11}B,5n) fusion-evaporation reaction and were performed at the TANDAR Laboratory in Buenos Aires. γ-γ Compton

---

*Deceased.

0556-2813/93/48(5)/2246(6)/$06.00 ©1993 The American Physical Society

suppressed (CS) coincidences and γ-beam time distributions were measured through the ^{206}Pb(^{11}B,3n) reaction at 55 MeV using the Nuclear Structure Facility at the State University of New York at Stony Brook.

Two delayed transitions of 11(2) and 174(20) ns were assigned to ^{214}Fr by means of excitation functions and γ-γ coincidences. The half-life of these two isomers was obtained via a ^{11}B pulsed-beam measurement. The γ-γ coincidences were performed with the Stony Brook 30% CS HPGe and BGO filter array. Three representative gates are shown in Fig. 1. The conversion electron measurement was made through the ^{208}Pb(^{11}B,5n)^{214}Fr at 73 MeV with a permanent magnet BaFe miniorange filter in conjunction with a liquid-N$_2$–cooled Si(Li) (300 mm^2 × 2 mm) detector positioned at 135° with respect to the beam direction. The conversion coefficient results are summarized in Table I.

Excited states in ^{214}Fr were studied and a level scheme up to an excitation energy of 3.6 MeV (Ref. [20]) was established (see Fig. 2). The excitation energies in ^{214}Fr are given relative to the $I^\pi = (9^-)$ state. An intense γ ray of 471.8 keV, which is in delayed coincidence with all the transitions assigned to ^{214}Fr and decays with a half-life of 174(20) ns, is hence proposed to establish an isomeric state (see Fig. 2). This transition is the most important line in the conversion electron spectrum (Fig. 3) and has $M2$ character (Table I). The strong 1023.0 keV $E3$ transition and the competing 580.5 keV $M2$ line, both decaying with a half-life of 11(2) ns (see Fig. 2), establish the second isomeric level at 1494.8 keV excitation energy.

The other transitions below the 1495 keV level have all $M1$ or $E2$ character. An intensity balance does not allow an unambiguous determination of the sequence of the 143.3 and 299.2 keV transitions. Their relative position in the level scheme was fixed by the parallel 607.0 and 906.5 keV weak transitions, and an indication of the deexcitation of the 1378 keV level through the 53.2 keV line, observed in coincidence spectra. The multipolarities of the 71.5($M1$) and 135.1($E2$) keV transitions which de-

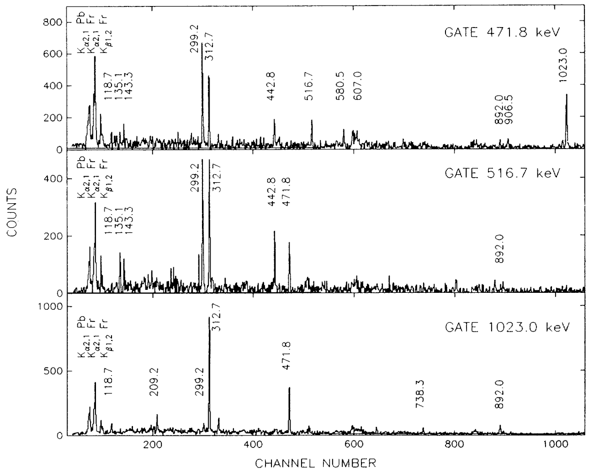

FIG. 1. Gamma-ray spectra gated on three representative transitions assigned to ^{214}Fr. The spectra correspond to the ^{206}Pb(^{11}B,3n) reaction at 55 MeV.

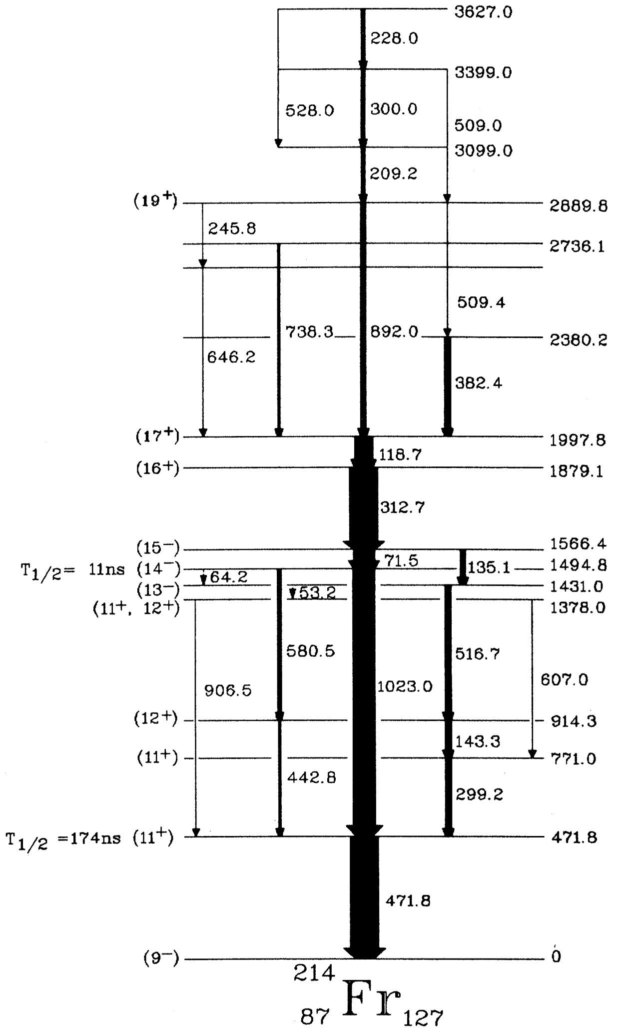

FIG. 2. Experimental level scheme of ^{214}Fr from the present study. The excitation energies are given relative to the $I^\pi = (9^-)$ state.

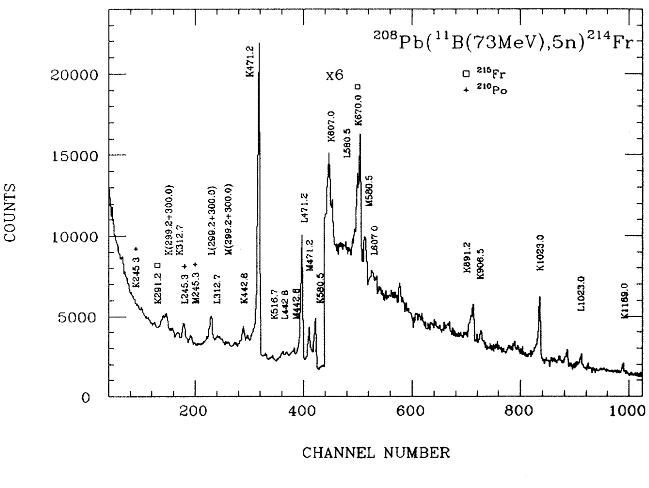

FIG. 3. Conversion electron spectrum from the reaction ^{208}Pb(^{11}B,5n)^{214}Fr at 73 MeV.

populate the 1566 keV state were assigned by intensity balance in coincidence spectra and similarly for the 118.7 keV line.

The $E1$ character of the 312.7 keV line follows from the conversion coefficient measurement and the relative position of this and the 118.7 keV transitions follows from coincidence intensity considerations.

The part of the scheme above the 1997.8 keV level is substantiated by the γ-γ coincidence data. The relative weakness of these lines only allows to tentatively assign a spin-parity of (19^+) to the 2898.8 keV level (from the $E2$ multipolarity of the 892.0 keV line).

TABLE I. γ-ray energies and intensities, theoretical (Ref. [29]) and experimental conversion coefficients, total transition intensities, and adopted multipolarities. The electron data correspond to the ^{208}Pb(^{11}B,5n) ^{214}Fr reaction at 73 MeV.

E_γ [a] (keV)	I_γ	α_K^{th} $E1$ $E2$ $M1$	α_K^{exp}	α_L^{th} $E1$ $E2$ $M1$	α_L^{exp}	α_M^{th} $E1$ $E2$ $M1$	α_M^{exp}	I^{Tot}	Adopted Multip.
53.2	0.7(2)							1.1(2)	$E1$[d]
64.2	0.9(2)							9(2)	$M1$[d]
71.5	8(2)							75(15)	$M1$[d]
118.7	6.0(4)							61(4)	$M1$[d]
135.1[b,c]	3.4(7)							12(2)	$E2$[d]
143.3	1.7(3)							16(3)	$M1$[d]
209.2[b,c]	11(2)								
228.0	3.0(5)								
299.2	13(2)	0.028 0.070 0.590	0.45(18)	0.005 0.056 0.116	0.16(6)	0.0011 0.015 0.028	0.048(20)	22(4)	$M1$
300.0[b]	9(2)								
312.7	100(5)	0.024 0.060 0.470	0.032(13)					100(8)	$E1$
382.4	12(2)								
442.8	5.2(6)	0.012 0.032 0.173	0.22(4)	0.0015 0.013 0.031	0.042(9)	0.0004 0.0036 0.008	0.0054(20)	5.4(6)	$M1$
471.8	63(3)	0.028($E2$) 0.182($M1$) 0.438($M2$)	0.41(8)	0.0123 0.031 0.103	0.10(2)	0.0028 0.007 0.025	0.023(4)	98(5)	$M2$
509.0[b]	3.5(7)							3.5(7)	$E2$[d]
516.7	19(3)	0.009 0.025 0.148	0.018(5)	0.0015 0.0102 0.023	0.004(2)			19(3)	$E1$
528.0[b]	3.5(7)							3.7(7)	$E2$[d]
580.5	7.4(7)	0.019($E2$) 0.115($M1$) 0.300($M2$)	0.23(4)	0.006 0.019 0.068	0.073(15)	0.0015 0.0036 0.017	0.037(8)	10(1)	$M2$
607.0[b]	2.6(5)	0.0064 0.021 0.101	0.21(5)					3.0(6)	$M1$
738.3	11(2)								
892.0	47(9)	0.0035 0.0091 0.0366	0.0070(10)					15(3)	$E2$
906.5	3.0(3)	0.003 0.008 0.034	0.039(8)	0.0004 0.0020 0.0060	0.0065(12)			4.0(4)	$M1$
1023.0	84(4)	0.0231($M1$) 0.0524($M2$) 0.0147($E3$)	0.015(3)	0.004 0.0103 0.0046	0.0042(8)	0.0009 0.0025 0.0012	0.0008(3)	84(4)	$E3$

[a] Errors in E_γ are about 0.2 keV.

[b] Contaminated lines. Relative intensities were deduced from coincidence spectra.

[c] Theoretical values from Ref. [29].

[d] The multipolarities result from an intensity balance in coincidence spectra.

III. DISCUSSION

Figure 4 shows the one-quasiparticle energies for neutrons (a), E_ν, and protons (b), E_π, vs the number of protons and neutrons, respectively, above the $N = 126$, $Z = 82$ double magic gap, relative to the ground state of each nucleus [namely, relative to $E_{\pi h_{9/2}}$ ($E_{\nu g_{9/2}}$) for the odd proton (neutron) nuclei]. From this information it is possible to obtain a zero-order estimate for the excitation energies in $^{214}_{87}\mathrm{Fr}_{127}$. The relevant proton energies are obtained from ^{213}Fr and the neutron energies from ^{213}Rn. For the $\nu i_{11/2}$ orbit in ^{213}Rn extrapolated values were used due to lack of experimental information on one-quasiparticle energies. The zero-order energies in ^{214}Fr are given in Table II where each entry corresponds to a degenerate $(j_\pi \otimes j_\nu)_{J^\pi}$ multiplet.

On the other hand, the matrix element of the effective p-n force, $V^{\mathrm{eff}}_{J^\pi=9^-}$, between the unpaired $h_{9/2}$ proton and $g_{9/2}$ neutron quasiparticles in the ^{214}Fr (or other doubly odd cases) (9^-) state is given by the difference between the p-n separation energy S_{np} relative to the ^{212}Rn core and the proton and neutron separation energies from the ^{213}Fr and ^{213}Rn ground states, respectively (see Table III):

$$S_{np}(Z+1,N+1,J) - S_{j_\nu}(Z,N+1) - S_{j_\pi}(Z+1,N)$$

$$= -V^{\mathrm{eff}}_{J=9^-} = M(Z,N) - M(Z+1,N+1) - [M(Z,N) - M(Z,N+1)] - [M(Z,N) - M(Z+1,N)]. \quad (1)$$

$S_{j_\nu}(S_{j_\pi})$ are the neutron (proton) separation energies and M's the masses [21] of the different nuclei.

The difference between the excitation energy, E^*, of a state of spin J in the doubly odd nucleus associated predominantly with one configuration $(j_\pi \otimes j_\nu)_{J^\pi}$ and the zero-order energy $E_\pi + E_\nu$, is a measure of the effective residual proton-neutron interaction $V^{\mathrm{eff}}_{J^\pi}$, correcting for the proton-neutron force in the (9^-) state. The equation expressing these relations is:

$$E^* - E_{j_\pi} - E_{j_\nu} + V^{\mathrm{eff}}_{9^-} = V^{\mathrm{eff}}_{J^\pi}. \quad (2)$$

The values of $V^{\mathrm{eff}}_{J^\pi}$ so obtained are given in Table III for the three isotones ^{210}Bi (which is nearest to the bare p-n force), ^{212}At and ^{214}Fr.

The largest amplitude in the wave function of the (9^-) state in ^{214}Fr is most likely associated with the stretched coupling $(\pi h_{9/2} \otimes \nu g_{9/2})_{9^-}$. In this configuration it is reasonable to expect that the p-n effective interaction is small [14], due to the fact that the proton Fermi level is approximately in the middle of the $h_{9/2}$ shell corresponding to occupation amplitudes, $v_\pi = u_\pi = 1/\sqrt{2}$, while the neutron Fermi level lies at the beginning of the $g_{9/2}$ shell. It is worth recalling that the expression for the effective p-n interaction becomes (Ref. [22]) $V^{\mathrm{eff}}_{J^\pi} = u_\pi^2 V_{J^\pi} + v_\pi^2 V^{-1}_{J^\pi}$ where $V_{J^\pi} = \langle (j_\pi \otimes j_\nu)_{J^\pi} | V_{p\text{-}n} | \rangle$ and $V^{-1}_{J^\pi} = \langle (j^{-1}_\pi \otimes j_\nu)_{J^\pi} | V_{p\text{-}n} | \rangle = -V_{J^\pi}$. This is borne out in the first row of Table III: $V^{\mathrm{eff}}_{J^\pi} = -199$ keV as compared to the bare value -398 keV in ^{209}Bi.

The $I^\pi = (11^+)$ assignment for the first excited state follows from the $M2$ character of the isomeric transition of 472 keV and its most probable configuration is $(\pi i_{13/2} \otimes \nu g_{9/2})_{11^+}$. One expects in this case a strongly attractive p-n interaction due to the particle character of both excitations, which turns out to be -832 keV, relatively close to the ^{210}Bi value. With these assignments the M2 character of the 472 keV transition is associated to the proton orbit change $\pi i_{13/2} \longrightarrow \pi h_{9/2}$. The $B(M2) = 12.6(1.4)\mu_N^2$ fm^2 [the Weisskopf value is $B(M2)_W \simeq 60\mu_N^2$ fm^2] obtained from the experimental

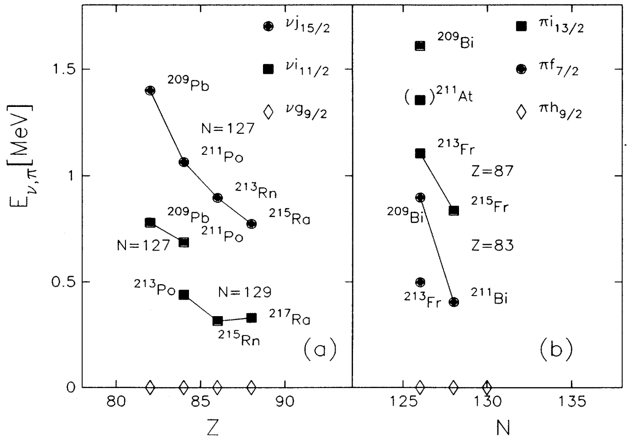

FIG. 4. Single quasiparticle energy evolution for protons (a) and neutrons (b) beyond the doubly closed shells, $Z = 82$ and $N = 126$. All energies are relative to the $\nu g_{9/2}$ and $\pi h_{9/2}$ ground states.

TABLE II. Zero-order excitation energies for seniority-2 configurations in ^{214}Fr. The proton (neutron) single quasiparticle energies are taken from ^{213}Fr (^{213}Rn) and are measured relative to their ground states (see text).

E_π (keV)	$h_{9/2}$	$f_{7/2}$	$i_{13/2}$
E_ν (keV)	0	498	1105
$g_{9/2}$ 0	0	498	1105
$i_{11/2}$ 570	570	1068	1675
$j_{15/2}$ 896	896	1394	2001

TABLE III. $V^{\mathrm{eff}}_{p\text{-}n}$ matrix element evolution for (in keV) some relevant two-quasiparticle configurations in the N=127 isotones ^{210}Bi, ^{212}At, and ^{214}Fr (see text).

	$V^{\mathrm{eff}}_{J^\pi}$ (keV)		
Configuration	^{210}Bi	^{212}At	^{214}Fr
$(\pi h_{9/2} \otimes \nu g_{9/2})_{9^-}$	-398	-265	-199
$(\pi i_{13/2} \otimes \nu g_{9/2})_{11^+}$	-961	(-957) [a]	-832
$(\pi h_{9/2} \otimes \nu j_{15/2})_{12^+}$	-622	-280	-181
$(\pi i_{13/2} \otimes \nu j_{15/2})_{14^-}$	-966	b	-705

[a] Tentatively assigned in ^{212}At (Ref. [11]).
[b] The 14^- state is not known in ^{212}At.

half-life, $T_{1/2}$ = 174(20) ns of the (11^+, 472 keV) level is in fact comparable to the $B(M2)$ = $18(12)\mu_N^2$ fm^2 extracted [17] from the 1.608 MeV transition in ^{209}Bi, which is normally associated with the single particle transition between the $i_{13/2}$ and $h_{9/2}$ proton orbitals. The value in ^{214}Fr is very similar to those measured in the odd-odd nuclei ^{212}At (Ref. [13]), ^{216}Fr (Ref. [23]) and ^{218}Ac (Ref. [14]).

The other isomeric state assigned in the present work is the (14^-) at 1495 keV with a half-life of $T^{1/2}$ = 11(2) ns. It decays mainly through an enhanced E3 transition of 1023 keV with a $B(E3) \simeq 83(15)10^3$ e^2 fm^6 ($\simeq$ 30 Weisskopf units), which is very similar to the value for the $\nu j_{15/2} \longrightarrow \nu g_{9/2}$ transition in ^{209}Pb [$B(E3) \simeq 70(20)10^3$ e^2 fm^6 (Ref. [24])]. The suggested configuration is $\left(\pi i_{13/2} \otimes \nu j_{15/2}\right)_{14^-}$. It has the maximum possible spin within the available seniority two proton-neutron configuration space defined in Table II. The excitation energy of this state implies, within this simple picture, an attractive p-n interaction of the order of -705 keV, similar to the situation for the (11^+) state to which it decays. The admixture of a collective octupole component $\left(3^- \otimes \nu g_{9/2}\right)$ into the particle state $\nu j_{15/2}$ (and $3^- \otimes \nu j_{15/2}$ into $\nu g_{9/2}$) is most likely responsible for the observed enhancement of the $E3$, 1023 keV, transition given the similarity to ^{209}Pb. The 3^- in this case corresponds to the particle-hole phonon of ^{208}Pb (Ref. [25]). Obviously a more sophisticated calculation allowing for the phonon admixture may modify the value of the estimated p-n force.

The only seniority-two configurations which can contribute to the (12^+) state at 914 keV are $\left(\pi h_{9/2} \otimes \nu j_{15/2}\right)$ and $\left(\pi i_{13/2} \otimes \nu i_{11/2}\right)$, the first one being the more likely candidate due to its lower zero-order energy (though this conclusion has to be taken with caution because of the possible presence of differing contributions from the p-n force). The isomeric (14^-) decays to this (12^+) state through an $M2$ transition of 580.5 keV with a $B(M2)$ of $5.5(1.0)\mu_N^2$ fm^2. The comparison of this value with the $B(M2)$ = $18(12)\mu_N^2$ fm^2 for the $\pi i_{13/2} \longrightarrow \pi h_{9/2}$ in ^{209}Bi (Ref. [17]) and $B(M2)$ = $33(8)\mu_N^2$ fm^2 for the $\nu j_{15/2} \longrightarrow \nu i_{11/2}$ in ^{209}Pb (Ref. [24]), might suggest a larger $\left(\pi h_{9/2} \otimes \nu j_{15/2}\right)$ component in the (12^+) state, although a destructive interference of both terms cannot be ruled out (Ref. [26]).

The large attractive values for the proton-neutron effective force in the $(\pi i_{13/2} \otimes \nu g_{9/2})_{11^+}$ and $(\pi i_{13/2} \otimes \nu j_{15/2})_{14^-}$ terms imply that the occupation of the $\pi i_{13/2}$ and $\nu j_{15/2}$ orbits will tend to increase significantly in the light actinide open-shell nuclei beyond the zero p-n force occupation values, thus providing a microscopic basis for the development of valence-shell octupole collectivity connected with a coherent superposition of two-quasiparticle states like $\nu(j_{15/2}g_{9/2})$ and $\pi(i_{13/2}f_{7/2})$. This reasoning resembles the Federman-Pittel (Ref. [27]) mechanism for the quadrupole degree of freedom and is in line with the discussion in Ref. [28] about the onset of collectivity, in particular, in the actinide region. In fact the interaction between $\pi h_{9/2}$ and $\nu g_{9/2}$ is comparatively weak in comparison to the n-n (or p-p) force (Ref. [28]) and significantly smaller than the one between the $\pi i_{13/2}$ and $\nu g_{9/2}$, $\nu j_{15/2}$ orbits. Apparently the appearance of octupole collectivity requires at least 5 protons and 3 neutrons outside closed shells as shown in a study on ^{216}Fr (Ref. [15]).

IV. CONCLUSIONS

^{214}Fr has been studied using γ-ray and e^- spectroscopy techniques following the ^{206}Pb(^{11}B,3n) and ^{208}Pb(^{11}B,5n) reactions. A completely new near-yrast level scheme has been obtained for ^{214}Fr up to an excitation energy of 3.6 MeV. Starting from the spin and parity assignments, and the half-life measurements, dominant configurations for several states are suggested and estimated values for the effective proton-neutron interaction are extracted suggesting a relation between the onset of collectivity and the strong proton-neutron force acting between $\pi i_{13/2}$ and $\nu g_{9/2}$, $\nu j_{15/2}$ single particle states which thus promotes the occupation of the intruder orbits $\pi i_{13/2}$ and $\nu j_{15/2}$.

A.J.K., J.D., and M.D. acknowledge the financial support of the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina.

---

[1] A.R. Poletti, G.D. Dracoulis, A.P. Byrne, A.E. Stuchbery, and J. Gerl, Nucl. Phys. **A473**, 595 (1987).

[2] A.E. Stuchbery, G.D. Dracoulis, A.P. Byrne, and A.R. Poletti, Nucl. Phys. **A486**, 397 (1988).

[3] T. Lönnroth, C.W. Beausang, D.B. Fossan, L. Hildingson, W.F. Piel, Jr., and E.K. Warburton, Phys. Scr. **39**, 56 (1989).

[4] A.P. Byrne, G.D. Dracoulis, C. Fahlander, H. Hubel,

A.R. Poletti, A.E. Stuchbery, J. Gerl, R.F. Davie, and S.J. Poletti, Nucl. Phys. **A448**, 137 (1986).
[5] T.P. Sjoreen, U. Garg, and D.B. Fossan, Phys. Rev. C **21**, 1838 (1980); H. Bohn, E. Endres, T. Faestermann, and P. Kienle, Z. Phys. A **302**, 51 (1981).
[6] N. Schulz, S. Khazrouni, A. Chevallier, J. Chevallier, L. Kraus, I. Linck, D.C. Radford, J. Dudek, and W. Nazarewicz, J. Phys. (London) G **10**, 1201 (1984); M.W. Drigert, J.A. Cizewski, and M.S. Rosenthal, Phys. Rev. C **32**, 136 (1985).
[7] D.J. Decman, H. Grave, H. Kluge, and K.H. Maier, Z. Phys. A **310**, 55 (1983).
[8] Y. Itoh, Y. Gono, T. Kubo, M. Sugawara, and T. Nomura, Nucl. Phys. **A410**, 156 (1983).
[9] T. Lönnroth and C. Baktash, Phys. Scr. **28**, 459 (1983).
[10] E. Ruchowska, J. Zylicz, C.F. Liang, P. Paris, and Ch. Briancon, J. Phys. (London) G **16**, 255 (1990).
[11] Nucl. Data Sheets **55**, 665 (1988), and references therein.
[12] Nucl. Data Sheets **63**, 79 (1991); **65**, 209 (1992); **65**, 4 (1993); **66**, 669 (1992); **66**, 171 (1992), and references therein.
[13] T. Lönnroth, V. Rahonnen, and B. Fant, Nucl. Phys. **A376**, 29 (1982).
[14] M.E. Debray, M. Davidson, A.J. Kreiner, J. Davidson, G. Falcone, D. Hojman, and D. Santos, Phys. Rev. C **39**, R1193 (1989); and (unpublished).
[15] M.E. Debray, J. Davidson, M. Davidson, A.J. Kreiner, D. Hojman, D. Santos, K. Ahn, D.B. Fossan, Y. Liang, R. Ma, E.S. Paul, W. Piel, and N. Xu, Phys. Rev. C **41**, R1895 (1990).
[16] N. Schulz, V.R. Vanin, A.J. Kreiner, E. Ruchowska, M. Aïche, Ch. Briancon, A. Chevallier, J. Chevallier, M.E. Debray, and C.J. Sens, Z. Phys. A **339**, 325 (1991).
[17] *Table of Isotopes*, edited by M.C. Lederer and V.S. Shirley (Wiley, New York, 1978), 7th edition.
[18] L.J. Jardine and A.A. Shihab-Eldin, Nucl. Phys. **A244**, 34 (1975).
[19] A.P. Byrne, A.M. Baxter, G.D. Dracoulis, B. Fabricius, T. Kibédi, K. Schiffer, and A.E. Stuchbery, Annu. Rep. (ANU-P/1081) 57 (1990); Annu. Rep. (ANU-P/1101) 66 (1991), edited by A.E. Stuchbery, Department of Nuc. Phys., Research School of Phys. Sciences, Australian National University, A.P. Byrne, G.D. Dracoulis, G.J. Lane, B. Fabricius, T. Kibédi, A.E. Stuchbery, A.M. Baxter, and K. Schiffer, *Book of Abstracts*, Contribution No. 1.2.45 (International Nuclear Physics Conference, Wiesbaden, Germany, 1992).
[20] M.E. Debray, A.J. Kreiner, J. Davidson, M. Davidson, J.M. Kesque, M. Ozafrán, A. Romo, H. Somacal, M.E. Vázquez, D.B. Fossan, Y. Liang, R. Ma, E.S. Paul, W. Piel, and N. Xu, in Proceedings of the Annual Meeting of the Argentine Physical Association 3.7 44, 1991 (unpublished); *Book of Abstracts* [19], Contribution No. 1.2.43.
[21] A.H. Wapstra and G. Audi, Nucl. Phys. **A432**, 1 (1985).
[22] A.J. Kreiner, Phys. Rev. C **22**, 1570 (1980).
[23] M.E. Debray *et al.* (unpublished).
[24] C. Ellegaard, J. Kantele, and P. Vedelsby, Nucl. Phys. **A129**, 113 (1969).
[25] Aa. Bohr and B.R. Mottelson, *Nuclear Structure* (Benjamin, New York, 1969), Vol 2.
[26] R.D. Lawson, *Theory of the Nuclear Shell Model* (Clarendon, Oxford, England, 1980), p. 294.
[27] P. Federman and S. Pittel, Phys. Lett. **69B**, 385 (1977); **77B**, 29 (1978); **82B**, 9 (1979); Phys. Rev. C **20**, 820 (1979).
[28] A.J. Kreiner and C. Pomar, Phys. Rev. C **36**, 463 (1987).
[29] F. Rösel *et al.*, At. Data Nucl. Data Tables **21**, 293 (1978).