Electron capture and positron decay of ^{206}Fr and ^{208}Fr and the energy levels of ^{206}Rn and ^{208}Rn

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The isotopes ^{206}Fr and ^{208}Fr were produced by the reactions Ir(^{20}Ne,xn)^{206,208}Fr and mass separated on-line. The electron-capture and positron decays to ^{206}Rn and ^{208}Rn were studied by collecting γ ray and internal conversion electron singles spectra as a function of decay time as well as γ-γ, γ-e^-, and γ-x ray coincidence spectra. The energies and many of the spins were determined for 18 excited, even parity states in ^{208}Rn and for 10 excited, even parity states in ^{206}Rn. These nuclei appear to be excellent candidates for interpretation in terms of a weak coupling shell model. The energy levels were also compared to the predictions of the interacting boson approximation model.

[RADIOACTIVITY ^{206,208}Fr from mass separated products of ^{nat}Ir(^{20}Ne,xn)^{206,208}Fr. Measured E_γ, ICC, γ-γ-t, $e^-\gamma$-t. Deduced levels E, J, π in ^{206,208}Rn.]

I. INTRODUCTION

The most useful experimental nuclear structure data for the stimulation of our theoretical understanding of nuclei are those which illuminate systematic trends. Of particular interest in this regard are data which yield the energy level structure of a series of isotopes of like Z but differing by an even number of neutrons. This gives rise to more sensitive tests of theoretical models than the knowledge of the level structure of an isolated nuclide on the N-Z plane. Such systematic knowledge is particularly valuable in testing nuclear models which have parameters which must be fixed experimentally. The parameters can be fixed using data on one nucleus in the chain and the accuracy with which properties of other members are predicted can be readily seen.

The experimental study of even-even neutron-deficient Rn nuclei is of particular interest in testing the interacting boson approximation (IBA) of Arima and Iachello,[1,2] and in testing weak coupling approximations to the full nuclear Hamiltonian, such as that of Hecht *et al.*[3] These models have met with extensive success for several series of nuclei but have not been tested extensively for $Z>82$ due to the paucity of nuclear structure information. Of the two nuclei selected for this investigation, ^{206}Rn has been studied with in-beam spectroscopy by Inamura *et al.*,[4] Backe *et al.*,[5] and Horn *et al.*,[6] while the only previous study of ^{208}Rn was reported in Ref. 5. The only levels and transitions reported in these previous studies were those of the yrast cascades and in the case of ^{206}Rn, all three level schemes were in conflict.[4-6]

The major goals of the present investigation were to study the low energy level structure of ^{206,208}Rn populated by the electron-capture and positron decay of ^{206,208}Fr and to attempt an interpretation in terms of shell model states or the level structures predicted by the IBA model. Earlier theoretical descriptions of these nuclei[7] were hampered by the lack of experimental nuclear structure information.

II. EXPERIMENTAL PROCEDURE

The isotopes ^{206,208}Fr were produced via the reactions ^{nat}Ir(^{20}Ne,xn)^{206,208}Fr with ^{20}Ne^{5+} beams from the Oak Ridge Isochronous Cyclotron (ORIC). The data were collected in five runs totaling 150 h and using Ne beams of 113, 111, 119, 122, and 120 MeV, respectively. The average beam intensities were approximately 200 particle nanoamperes of heavy ion beam on the target of natural iridium evaporated onto graphite felt. Production rates of from 10^4 to 10^5 nuclei per second were observed. The target was located inside one of two types of thermal ionization sources developed at UNISOR.[8] The reaction products were separated with the on-line UNISOR, 90°-Danfysik mass separator and deposited on a Mylar tape. The deposited source on the tape was moved periodically under computer control to detector stations after a predetermined collection time. The beam intensity was periodically monitored by mechanical introduction of a

TABLE I. Coincidence relationships established by gamma-gamma gates for ^{208}Rn transitions. "x" denotes appearance of given line in gated spectra. "?" denotes marginal significance. Only gates with adequate statistics to deduce coincidence relationships are shown.

Gated energy (keV)	Gamma energy (keV)																		
	89	225	299	325	335	389	470	492	511	553	636	671	691	717	720	778	887	943	990
225				x						x	x								
299								x	x										
325	x	x			x		x		?		x			?	x	x			
335				x					x		x								
389				x					x	x	x					x			
470										x	x	x							
492			x						x										
553		x	x	x		x	x				x	x		x					x
636	x	x		x	x	x	x	x		x	x		x	x	x	x	x	x	x
671							x			x	x								
690				x					?	x	x								
717				?						x	x					?			
720				x						x	x					x			
778	x			x	x	x		x			x		x						
943											x					x			
990										x	x								

beam stop located a short distance in front of the target. In addition, the activity at the collection point was constantly monitored with a NaI(Tl) detector. The efficiency of the ion source resulted in about 30% of this yield at the collection point of the isotope separator where it was deposited onto aluminized Mylar tape. The collection times were generally chosen to be about three half-lives of the product nuclei of interest.

The detectors used were large Ge(Li) detectors, with energy resolutions full width at half maximum (FWHM) of 2.1 keV or less at 1.33 MeV, for γ-ray singles and γ-γ coincidence experiments and a Si(Li) detector for e^- singles and e^--γ coincidence and x-ray experiments. Standard spectroscopy and coincidence techniques were used. The coincidence apparatus consisted of two detectors, two fast timing filter amplifiers, two constant fraction discriminators, and a time-to-amplitude converter (TAC). The tape was moved between two detectors of the coincidence geometry and three signals were stored on magnetic tape: the spectroscopy amplifier outputs from each detector and the output of the TAC. The computer based data acquisition system has been described elsewhere.[9] In addition, the singles data were stored on disk in planes of data representing successive time periods after the activity arrived between the detectors. These data were used to determine the half-lives of the individual spectral lines to aid in identification and association with a given nuclide. The three pieces of information comprising a coincidence event were used to study γ-γ and γ-e^- time correlations and coincidences.

Energy calibration of the γ-ray detectors was accomplished with a mixed radioactive source of ^{57}Co, ^{60}Co, ^{85}Sr, ^{88}Y, ^{109}Cd, ^{113}Sr, ^{137}Cs, ^{139}Ce, and ^{203}Hg obtained from the National Bureau of Standards. The Ge(Li)-Si(Li) geometries used for internal conversion coefficient measurements were calibrated with a mixed source of ^{133}Ba and ^{207}Bi. The centroids and areas were determined using a version of the peak fitting routine called SAMPO[10] which can accommodate realistic, non-Gaussian shapes. The peak energies were determined to within 0.1 keV while the line intensities were determined to within 5%. The internal conversion coefficients were normalized to the known pure $E2$ ground state transition in the neighboring even-even polonium nuclei.

The coincidence relationships given in Tables I and II and the γ ray intensities were used to construct the decay schemes of ^{206,208}Rn. Feeding of excited levels in Rn directly from the Fr parent was suggested by noting the discrepancies between transition intensities populating and depopulating each level, after corrections were made for in-

TABLE II. Gamma ray transitions observed in ^{208}Rn. Theoretical internal conversion coefficients (ICC's) are from the Hager-Seltzer algorithm for the multipolarity shown in the last column.

Gamma ray energy (keV)	Relative photon intensity	Internal conversion coefficient ($\times 10^{-2}$) shell	experimental	theoretical	Multipolarity
88.9 ± 0.1	1.5 ± 0.3	L	1110 ± 170	1050	$E2$
225.5 ± 0.2	0.77 ± 0.10	K	122 ± 12	112	$M1$
298.7 ± 0.1	0.95 ± 0.10	K	29.1 ± 4.3	29.0	$M1+E2$ [a]
325.2 ± 0.2	53.2 ± 3.8	K	4.4 ± 0.2	5.8	$E2$
335.0 ± 0.3	12.3 ± 5.0	K	39.5 ± 16.0	38	$M1$
389.3 ± 0.3 [b]	4.0 ± 2.2	K	27.9 ± 10.0	25	$M1$
389.3 ± 0.3	2.8 ± 2.2	K	4.0 ± 2.0	4	$E2$
469.8 ± 0.1	5.7 ± 0.4	K	14.6 ± 1.5	15.1	$M1$
491.9 ± 0.1	2.8 ± 0.2	K	2.5 ± 0.5	2.5	$E2$
553.1 ± 0.1	31.0 ± 2.2	K	1.7 ± 0.1	2.0	$E2$
635.8 ± 0.2	100.0	K	1.4 ± 0.1	1.5	$E2$
636.3 ± 0.2	6.4 ± 2.8	K	1.4 ± 0.1	1.5	$E2$
671.6 ± 0.1 [c]	1.3 ± 0.9				
690.5 ± 0.1 [c,d]	2.2 ± 0.2				
716.8 ± 0.1	4.0 ± 2.8	K	2.5 ± 1.0	1.2	$E2$
719.6 ± 0.1	6.6 ± 0.5	K	1.1 ± 0.2	1.2	$E2$
778.5 ± 0.1	68.9 ± 4.9	K	1.0 ± 0.1	1.0	$E2$
887.3 ± 0.1 [c,d]	1.7 ± 0.4				
942.5 ± 0.1 [c,d]	4.6 ± 0.3				
990.1 ± 0.1 [c,d]	4.1 ± 0.8				

[a] Mixing ratio (δ^2) is 1.0 ± 0.2.
[b] Doublet line not resolvable. ICC's are based on $M1$ and $E2$ pure components.
[c] Insufficient data to deduce ICC.
[d] Line could not be assigned in decay scheme.

ternal conversion. The ordering of the transitions and levels was assigned, using the observed (γ ray $+e^-$) intensities, by requiring an intensity balance as well as consistency with the coincidence relationship tables. In this way, internally consistent decay schemes were constructed. Improper intensity balancing eliminates all but a very few possibilities for the correct decay scheme. An additional test was made by determining the transition intensities within the gates and comparing them with the intensities consistent with a given decay scheme.

III. RESULTS

The observed coincidence relationships for the γ rays in ^{208}Rn and ^{206}Rn are given in Tables I and II, respectively. All internal conversion electron measurements, summarized in Tables III and IV, were consistent with $M1$, $E2$, or mixtures of these two multipolarities. No evidence for any $E0$ transition was observed.

The information in Tables I–IV was used to construct the decay schemes discussed in more detail below. The coincidence intensity analyses applied to these decay schemes indicated that the schemes were internally consistent within experimental error. Examples of these analyses are given in Tables V and VI.

A. Decay of ^{208}Fr

Attention is now turned to a discussion of the deduced levels in the level scheme for ^{208}Rn, shown in Fig. 1, for which unique spin and parity assignments have been made.

1. The 635.8, 141.3, 1739.5, and 1828.4 keV levels

These levels represent the states previously reported by Backe *et al.*[5] The transitions (636, 778, 325, and 88.9 keV) connecting them compose the 8^+ to ground state (0^+) cascade as observed by Backe *et al.* The $E2$ multipolarities for all four transitions connecting these states unambiguously yield the spins and parity for these four levels.

2. The 1188.9 and 1825.2 keV levels

The 553.1 keV gamma ray is observed to be in coincidence with the 325.2 keV cascade gamma ray

TABLE III. Analysis of coincidence gates for ^{206}Rn transitions. "x" denotes appearance of given line in gated spectra.

Gate energy (keV)	Gamma energy (keV) 161	198	274	283	346	356	559	575	629	684	720	890	926
161				x			x	x	x				
198							x						
283	x						x	x	x				
346	x						x	x	x				
356								x		x			
559								x	x	x		x	
575	x		x	x			x		x	x	x		x
629	x			x	x		x	x					
684					x		x	x					
890				x			x	x					
926								x					

only through the 225.5 keV ($M1$) transition. Since no transition within the radon nucleus are observed to populate the 1825.2 keV level, that level must be fed directly by the electron capture decay of the ground state of ^{208}Fr. Since the spin of the francium parent nucleus has been determined[11] to be 7, the minimum physically probable spin for this level would be 6. These observations and the observed $E2$ multipolarity of the 553.1 and 636.3 keV gamma rays unambiguously determine the spin and parity of their associated levels.

3. *Other levels*

The spins of the levels at 1905.7, 2128.8, 2164.4, and 1459.1 keV, though not uniquely determined, are delimited by the absence of γ feeding within the nucleus—indicating direct ($EC+\beta^{+}$) feeding from the parent nucleus—and the angular momentum restrictions dually imposed by the electron capture feeding from the spin 7 ground state of ^{208}Fr and by the multipolarities of their associated transitions. These limits are shown at these levels in Fig. 1.

All other levels for which possible spins are shown are based solely on the angular momentum restrictions imposed by the multipolarities of the associated transitions. The TAC spectrum of the 88.9–325.2 keV cascade was analyzed by the slope method[12] and the half-life of the 8^{+} isomeric level at 1828.4 keV was determined to be 0.35 ± 0.22 μsec, consistent with a pure $E2$ transition. The magnitude of this half-life precluded the use of other techniques because of the limited TAC range used. The error quoted is the statistical error in the least-squares fit to the decay curve.

TABLE IV. Gamma ray transitions observed in ^{206}Rn. Theoretical internal conversion coefficients (ICC's) are from the Hager-Seltzer algorithm. Energies are in keV and have errors of ±0.1 keV. ICC's are for the multipolarities shown in the last column.

Gamma ray energy	Relative photon intensity	Shell	ICC ($\times10^{-2}$) Experimental	Theoretical	Multipolarity
161.4	10.0 ± 2.2	L	0.65 ± 0.07	0.681	$E2$
197.8 [a]	4.9 ± 1.0	K	0.34 ± 0.17	0.546	$E2$
274.9 [a]	2.4 ± 0.4				
282.6	8.3 ± 0.9	K	0.51 ± 0.07	0.60	$M1$
345.6	3.3 ± 1.4				
356.0	3.1 ± 2.0				
559.0	70.0 ± 2.1	K	0.015 ± 0.005	0.019	$E2$
575.3	100.0	K	0.013 ± 0.005	0.018	$E2$
628.6	31.0 ± 2.7	K	0.016 ± 0.005	0.015	$E2$
684.0	8.3 ± 2.1				
890.6	6.1 ± 2.0				
926.5	8.0 ± 2.0				

[a] Not placed in decay scheme.

TABLE V. Examples of coincidence intensity analysis for selected ^{208}Rn gates. Energies are in keV; errors are approximately 25% for all intensities.

Gated energy	Coincident transition energy	Relative intensity in gated spectrum	Relative intensity in gated spectrum calculated from decay scheme
325	89	3.0	2.8
	225	1.9	1.4
	389	6.6	7.5
	469	0.7	0.0
	553	1.9	3.0
	635	100	100
	720	2.3 [a]	12.8
	778	100	100
389	325	51	59
	511	28	
	553	47	41
	636	100	100
	778	76	59
553	225	4.6	2.4
	325	4.4	5.2
	389	7.5	10
	469	18	18
	511	4.1	
	636	100	100
	671	3.1	4.0
	718	35 [a]	13
	990	9.1	13

[a] Coincides with a sum peak; difficult to ascertain intensity.

B. Decay of ^{206}Fr

Based on the information contained in Tables II and IV, the decay scheme shown in Fig. 2 was deduced. The scheme was determined to be energy and intensity balanced. Additional confirmation was provided by a coincidence intensity analysis. The results obtained with the coincidence intensity analysis for several transitions are shown in Table VI.

The previous observations[4–6] of the four γ-ray cascade from the 1924.3 keV level, verified by the present data, allowed the following unique assignments: $J^\pi(575.3)=2^+$, $J^\pi(1134.3)=4^+$, $J^\pi(1762.9)=6^+$, and $J^\pi(1924.3)=8^+$. It was also determined that γ-ray feeding did not account for all of the in-

TABLE VI. Examples of coincidence intensity analysis for selected ^{206}Rn gates. Energies are in keV; errors are approximately 25% for all intensities.

Gated energy	Coincident transition energy	Relative intensity in gated spectrum	Relative intensity in gated spectrum calculated from decay scheme
282	161	84	100
	511	35	
	559	90	100
	575	100	100
	629	77	100
629	161	26	31
	282	23	23
	511	15	
	559	100	100
	575	97	100
684	356	36	37
	559	100	100
	575	88	100

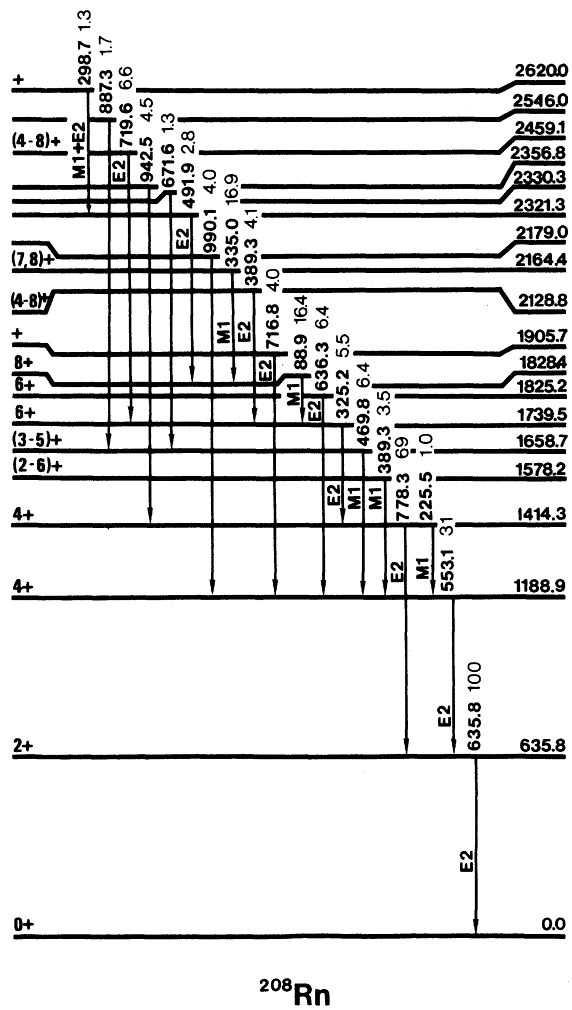

FIG. 1. Deduced level scheme for ^{208}Rn. Transition and level energies are in keV. Deduced transition multipolarities are indicated. Small numbers following transition energy denote relative transition intensities. The 942.5 keV line and the 2357 keV level are suspect due to poor statistics and contamination in that gate.

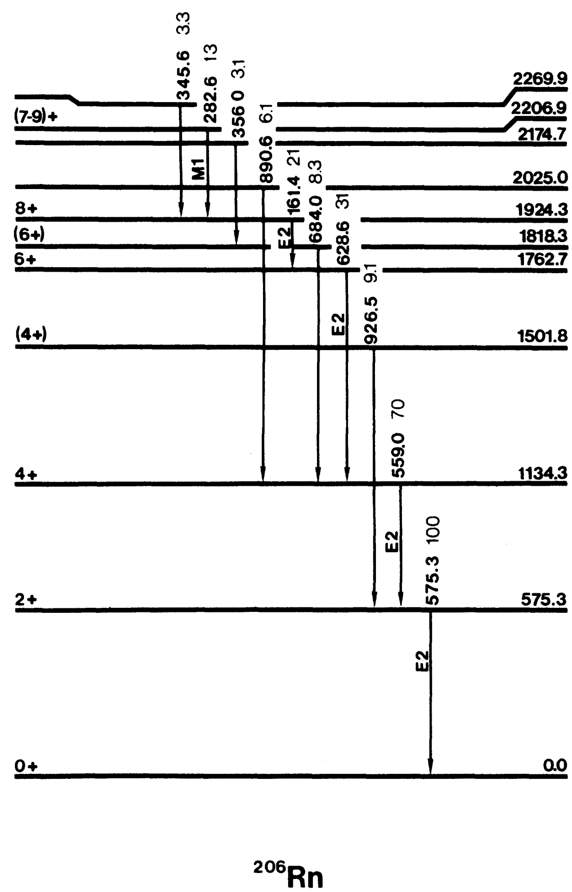

FIG. 2. Deduced level scheme for ^{206}Rn. Deduced transition multipolarities are indicated. Small numbers following transition energies denote relative transition intensities.

tensities of the 559.0 and the 628.6 keV γ rays; hence, it is concluded that direct feeding of the 1134.3 and 1762.9 keV levels by electron capture is very probable. This implies that the spin of the ^{206}Fr ground state is most probably 5.

The spin and parity of the 2206.9 keV level were delimited by the internal conversion data. The half-lives of the 8^+ level at 1924.3 keV and the 6^+ level at 1762.7 keV were measured by analyzing the TAC spectra from the 282.6–161.4–628.6 keV cascades. The spectra were analyzed using the centroid shift and deconvolution moment methods[12] with the results $T_{1/2}(1924.3) = 6.3 \pm 2.4$ and $T_{1/2}(1762.9) = 1.8 \pm 1.3$ ns.

IV. THEORETICAL CONSIDERATIONS

A general shell model treatment of nuclei in the region of the doubly magic ^{208}Pb nucleus is in principle very attractive because of the established stability of the ^{208}Pb core. The fact that there are many low-lying single particle levels with relatively high spins results in very large Hamiltonian matrices beyond the capability of current diagonalization techniques. McGrory and Kuo[13] have pointed out that the large neutron excess in this region leads one to the reasonable simplifying assumption that the neutron-proton interaction plays a relatively minor role. The plausibility of this assumption rests on the fact that the valence neutrons and protons mainly occupy very different orbits. The protons are filling the $g_{9/2}$ level while the neutron holes exist in the top of the shell where $J = \frac{1}{2}$ and $\frac{3}{2}$; hence the principal and orbital quantum numbers are not similar, which are the criteria for strong n-p interactions. The general approach is to treat the neutrons (or neutron holes) and protons separately in a standard shell model calculation and then to couple them via a so-called "weak coupling" of the protons, and in this case, neutron holes.

No such detailed calculations exist in the literature for ^{206,208}Rn; however, very simple arguments can be made from which it can be concluded that these nuclei are excellent candidates for such an interpretation. The ^{208}Rn nucleus can be pictured as the ^{208}Pb core with four neutron holes and four protons. In the weak-coupling scheme ^{208}Rn may be considered in a first approximation as being a mixture of the four neutron holes of ^{204}Pb and four protons of ^{212}Rn. The weak n-p coupling then must lower the first excited 2^+ state, for example, and with the correct interaction give the experimental spectrum of ^{208}Rn. The energy levels of ^{206,208}Rn along with their particle or hole neighbors which would participate in the weak coupling scheme are shown in Fig. 3.

Another approach to the interpretation of these nuclei is the IBA. We will not give a lengthy theoretical discussion here; however, for completeness, it is necessary to give a condensed introduction to the salient features of the model as well as a brief description of the symmetry limits which can be related to well known macroscopic models, for example, rotational or vibrational models. The IBA is based on the assumption that like valence nucleons couple through a dominant pairing interaction as they do, for example, in the BCS model. In the simplest version of the model nucleon pairs are assumed to couple to angular momentum $L=0$ or $L=2$. The coupled fermion pairs are called s and d bosons, respectively.

Using the s and d bosons, their six components span a six dimensional space and provide a linear basis for an SU(6) group representation. The group SU(6) has only three decompositions: SU(6) $\rightarrow$ SU(5) $\times$ U(1), SU(6) $\rightarrow$ SU(3) $\times$ SU(2), and SU(6) $\rightarrow$ O(6) $\rightarrow$ O(5) $\rightarrow$ O(3). These decompositions represent three limits of the Hamiltonian. If the s boson

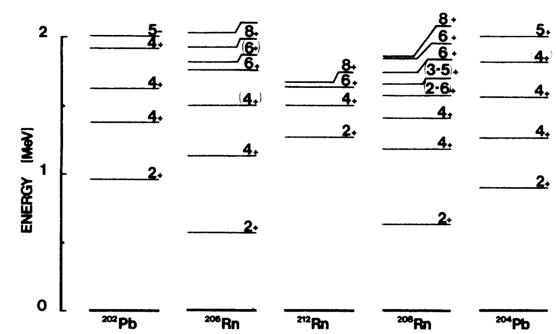

FIG. 3. Experimentally determined level schemes for ^{202}Pb, ^{206}Rn, ^{212}Rn, ^{208}Rn, and ^{204}Pb from Ref. 19.

degrees of freedom are neglected, only the second and third terms of the Hamiltonian are maintained involving only four parameters. This is called the SU(5) or d boson limit.[14,15] The energy spectra of this limit are typically vibrational. The other symmetry limits lead to rotational spectra[16] and a spectrum resembling a γ-soft vibrator.[17]

The use of the IBA in analyzing the deduced decay schemes must be undertaken with some caution. The nuclei studied lie near ^{208}Pb and the application of any collective model in fitting the nuclear level schemes may not represent a reasonable test of the overall value of the model or its underlying assumptions. An alternative approach, such as weak coupling, may provide a more complete explanation of the observed features of the nuclei, but such calculations have not been undertaken due to the lack of data in the region. The application of the IBA to the nuclei discussed here, then, represents only an initial theoretical explanation of the observed phenomena.

As a first approximation to a description of the more detailed level scheme of ^{208}Rn, analytical expressions representing each of the symmetry limits of the full Hamiltonian were applied to the spectrum of ^{208}Rn. This nucleus, with four protons and four neutron holes outside the ^{208}Pb core, would have four bosons. When the limit formulas were applied, only the SU(5) limit was found to properly order the levels observed experimentally by energy and spin. The 8^+ level at 1828.4 keV was not included in these or subsequent calculations since its probable two particle nature[5] would preclude an explanation of that state as the four d boson, 8^+ level in an IBA description.

Using a set of initial SU(5) parameters, the computer program PHINT[18] was used to calculate the theoretical spectrum using the full IBA Hamiltonian. The program allows the computer to vary any combination of the nine parameters to minimize the energy-weighted chi-square difference between the experimental and theoretical spectra. In the analysis used in this study, initially only the 0^+, 2^+, 4^+, and 6^+ levels were fit.

It was found that only five of the nine parameters are needed to achieve good agreement between theory and experiment for ^{208}Rn. These five parameters are the four SU(5) parameters and the coefficient for the term

$$(d^\dagger d^\dagger)^{(0)}(ss)^{(0)}+(dd)^{(0)}(s^\dagger s^\dagger)^{(0)}\ .$$

The theoretical spectrum obtained is compared with the experimental spectrum in Fig. 4. It is seen that the theoretical spectrum shows very good agreement with the observed spectrum, correctly predicting the known spins for the low lying states or predicting spins within the range of pos-

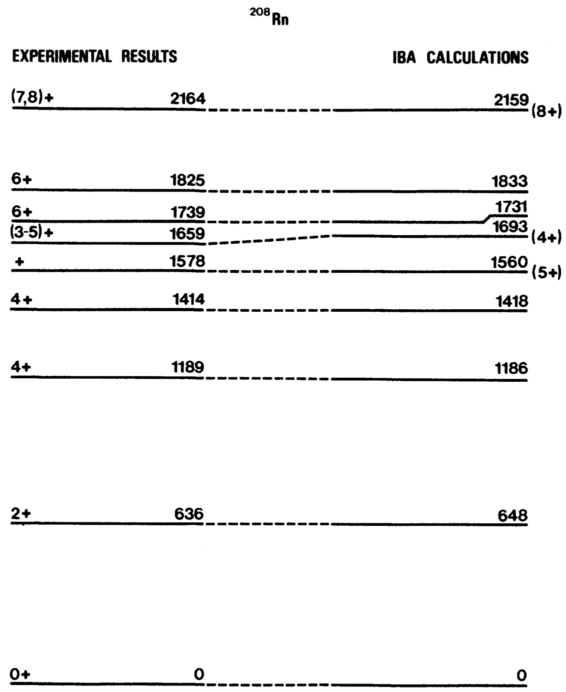

FIG. 4. Comparison of deduced level scheme for ^{208}Rn with the results of the IBA calculations. Energies are in keV. IBA levels which correspond to experimental levels are shown.

sible spins. Many more low spin states are predicted than are observed and are not shown in Fig. 4. The presence of these states cannot be ruled out based on this study since they would not be populated from the Fr ground state and would be "shielded" by the higher spin states. Additional efforts to find them must await further in-beam and decay studies.

Above the energy of the 8^+ isomeric level, the experimental level density in Fig. 1 can be seen to increase significantly. Such an increase generally occurs as a critical energy is reached above which noncollective effects dominate. In particular, at this energy it may be possible to break the closed core and excite nucleons from it. Since the IBA requires that boson number be conserved, spectra above this critical energy are not completely explicable in terms of the model. The IBA predicts only one state above this point, the 8^+ level, which appears to have been found in the experimental spectra.

There is insufficient experimental information at this time to assess predictions of the IBA for electromagnetic transitions. It can be noted, however, that the 778 keV, $4_2^+ \rightarrow 2^+$ transition is ruled out by the model. The 4_2^+ state is a three d boson state, while the 2^+ state is a single d boson state. As can be seen from the selection rules for $E2$ transitions,[14] the number of d bosons in a nucleus cannot change by 2 with an $E2$ transition. This state presents an important problem in interpreting the observed ^{208}Rn level scheme in terms of the IBA. There are two possible explanations: (a) the level may not be an IBA state, or (b) it may represent a new mode of excitation within the model, namely a ($L=4$) or "g" boson. A definite conclusion concerning the nature of this state must await further experimental data. Of particular value would be the measurement of the half-life of this state.

The level scheme deduced for ^{206}Rn in this study and that deduced for ^{204}Rn by Backe *et al.*[5] do not yet possess sufficient detail to permit as complete an analysis of their structures with the IBA as was possible for ^{208}Rn. Figure 5 shows the results of the IBA calculations performed for these nuclei using PHINT. For those levels deduced in the two nuclei, good agreement exists between theory and experiment. However, much greater detail in these two level schemes, particularly in ^{204}Rn, will be required if conclusions concerning the applicability of the IBA to these nuclei are to be complete. Also, as in the case of ^{208}Rn, electromagnetic transitions predicted by the IBA cannot be extensively tested at this time because there is still insufficient experimental data.

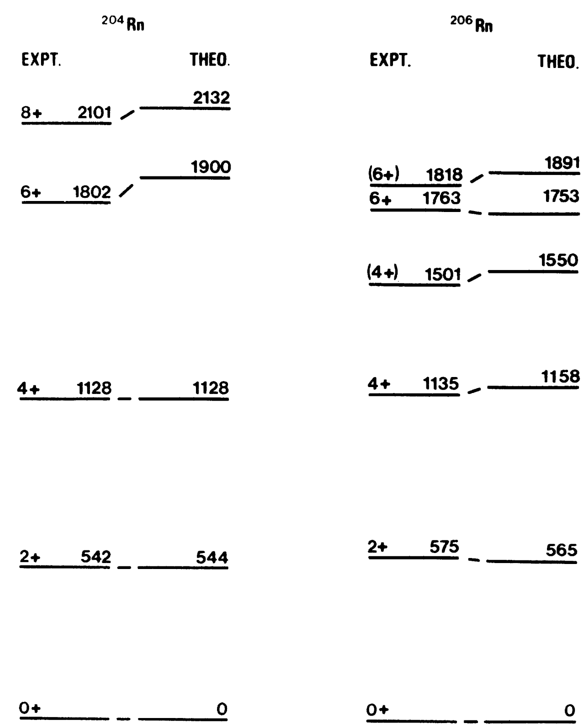

FIG. 5. Comparison of deduced level schemes for ^{204}Rn and ^{206}Rn with the results of IBA calculations. The ^{204}Rn level scheme is from Backe *et al.* (Ref. 5).

V. SUMMARY AND CONCLUSIONS

Nuclear spectroscopic techniques with mass separated sources of ^{206,208}Fr have permitted the unambiguous determination of the level schemes of ^{206,208}Rn with significantly more known levels, spins, and parities than previously determined. The theoretical interpretation of the levels of ^{206,208}Rn, in terms of a weak coupling shell model looks very promising. These level schemes also compared well to those predicted by the interacting boson approximation; however, there is still insufficient data on transition probabilities to test this aspect of the theory. Future experimental investigations of these and other nuclei in this region should probably concentrate on electromagnetic transition probabilities to subject the IBA to more stringent tests.

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