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Alpha-Decay Studies of the $N = 127$ Isotones ^{214}Fr, ^{215}Ra, and ^{216}Ac†

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The study of nuclei which are one neutron removed from the $N=126$ closed shell has shown that the odd-proton $N=127$ isotones α decay from both the ground state and a metastable state whose excitation energy decreases between ^{210}Bi and ^{216}Ac. The α-decay daughters of these nuclei show some correspondence in their energy-level spacings which is due to the coupling of specific single-particle configurations near the $N=126$ closed shell. New information has been obtained for the α decay of the 1− isomer of ^{214}Fr to levels in ^{210}At, and for the α decay of ^{216}Ac to levels in ^{212}Fr. The decay scheme of ^{216}Ac is markedly different from that reported by others. An experimental and theoretical study of the α decay of ^{215}Ra has also been made.

I. INTRODUCTION

Experimental investigations of the $N=125$ and $N=127$ isotones near the ^{208}Pb core are particularly interesting because of the relative simplicity of the states at low excitation energy. Theoretical[1-4] and experimental[5-8] studies of the energy levels of ^{208}Bi and ^{210}Bi have shown the importance of a residual neutron-proton tensor component in the shell-model force. It has also been demonstrated experimentally that the qualitative features of this interaction are retained at low excitation energies when proton pairs are added to these nuclei.[8-12]

The odd-proton $N=127$ isotones ^{210}Bi, ^{212}At, and

^{214}Fr α decay from the ground and a metastable state having spins 1− and 9−, respectively. These states are part of a multiplet arising from the $(2g_{9/2})_n\,(1h_{9/2})_p$ single-particle configuration. As proton pairs are added to ^{210}Bi, the excitation energy of the 9^- state decreases from 268 to 220 keV for ^{212}At and 123 keV for ^{214}Fr. Part of this investigation has been to extend the study of this state to include ^{216}Ac.

Studies of ^{208}Bi have shown that the energy levels below 1.2 MeV cluster into three distinct groups, each containing predominantly $(3p_{1/2})^{-1}{}_n\,(1h_{9/2})_p$, $(2f_{5/2})^{-1}{}_n\,(1h_{9/2})_p$, and $(3p_{3/2})^{-1}{}_n\,(1h_{9/2})_p$ single-particle configurations, respectively. It has previously been shown that the influence of these configurations is somewhat retained when a proton pair is added to ^{208}Bi to form ^{210}At. In the present work, we have studied these states in ^{212}Fr, populated from the α decay of ^{216}Ac. We have also obtained new information on the α decay of ^{215}Ra to levels in ^{211}Rn.

II. EXPERIMENTAL DETAILS

Irradiations of ^{209}Bi targets of 4-mg/cm^2 thickness by ^{11}B and ^{12}C ions were carried out at the Yale heavy-ion accelerator. The helium-jet-recoil-transport method[13,14] was used to detect nuclear-reaction product nuclei recoiling from the target. The recoils were thermalized in helium and were pumped at near sonic velocity through a capillary tube to a region of low background. The reaction products were directed onto a stainless-steel collection assembly where the helium carrier gas was pumped off. This technique produced a thin point source from which α particles were detected using a Si(Au) surface-barrier detector located 5 mm from the surface of the collector. The α-particle resolution of the detectors used in this work varied from 25–30 keV (full width at half maximum).

Precise peak positions were determined by fitting each group to a Gaussian distribution. Energy calibrations were made by fitting the peak positions of known α-group standards in the spectrum to a quadratic function to account for system nonlinearities.

The beam energy was varied by degrading the incident ions (10.6 MeV/nucleon) using Ni foils. Energies were calculated using the range-energy data of Northcliffe.[15] Since the excitation-function data were used for mass identification purposes only, no attempt was made to measure precise beam energies or absolute excitation functions.

Decay curves were measured between beam bursts which were 2 msec in duration at a frequency of 10/sec. Half-lives were obtained by fitting an exponential function to the data using a nonlinear least-squares technique and taking account of the finite collection time when necessary.

III. RESULTS AND DISCUSSION

A. ^{214}Fr

The α decay of the isomers of ^{214}Fr has been studied previously using the ^{208}Pb(^{11}B, $5n$)^{214}Fr reaction.[9] From these studies, several α groups were identified. However, the 1− ground-state decay was produced in much lower yield than the 9− metastable-state isomer. As a result, it was difficult to obtain detailed information on the ground-state decay due to the interference of other α groups in the spectrum.

In the present work, the ground state of ^{214}Fr was produced in high yield from the α decay of ^{218}Ac formed in the reaction ^{209}Bi(^{12}C, $3n$)^{218}Ac. An α-particle spectrum of the products produced by bombarding ^{209}Bi with 72-MeV (lab) ^{12}C ions is shown in Fig. 1. No α groups due to the unknown isotope ^{218}Ac were observed in the spectrum due to its very short half-life relative to the collection speed of the system (~2 μsec). The half-life of the ^{214}Fr ground state, however, is 5.0 msec,[9] which is well within the collection-time capability.

In addition to the two main α groups at 8.426 (93.0%) and 8.358 (4.7%) MeV, weaker groups at 7.937, 7.605, and 7.406 MeV were also found to be associated with the decay of ^{214}Fr. The assignments were based on the excitation-function measurements summarized in Fig. 2. Maximum cross sections were observed at a bombarding energy where the yield for the parent ^{218}Ac produced by a (^{12}C, $3n$) reaction was expected to be the greatest. These excitation functions differ quite markedly from that measured for the 8.546-MeV group aris-

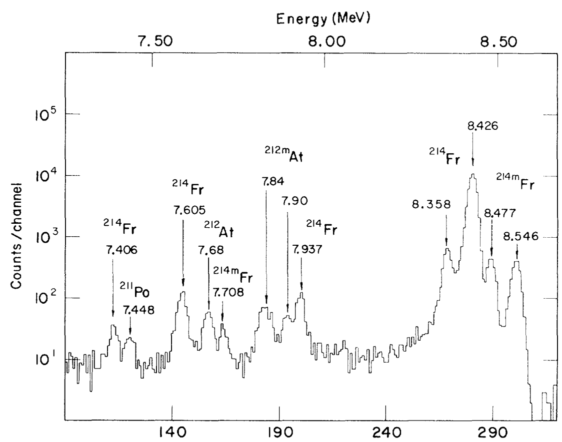

FIG. 1. α-particle spectrum of products of the ^{209}Bi + ^{12}C reaction at 72-MeV bombarding energy.

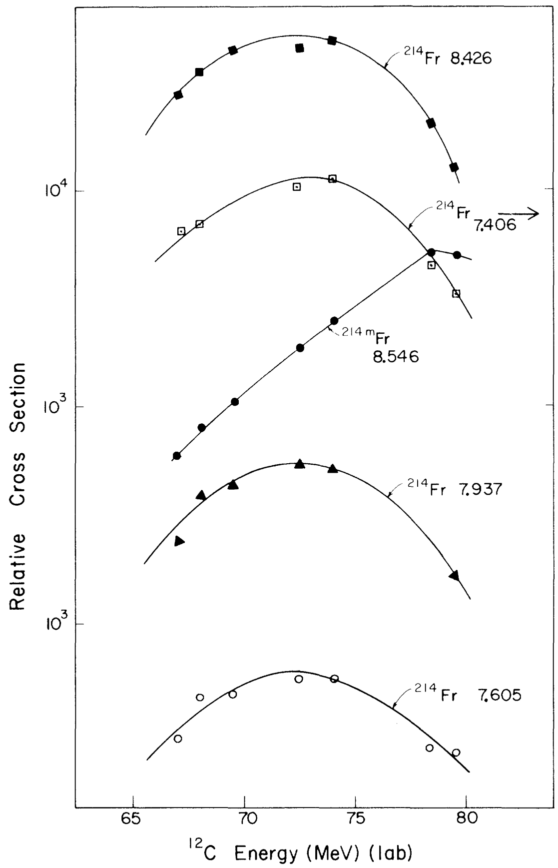

FIG. 2. Excitation functions for the α groups of ^{214}Fr produced in ^{209}Bi + ^{12}C bombardments.

ing from the 9- metastable state of ^{214}Fr produced directly by a (^{12}C, $\alpha 3n$) reaction.[16] It appears from our data that ^{218}Ac does not populate the 9- isomer of ^{214}Fr, indicating that the ground state of ^{218}Ac is probably low J and that no α-emitting high-spin isomeric state exists.

In the previous study using the ^{208}Pb + ^{11}B reaction to produce ^{214}Fr, several intense groups due to ^{211}Po and ^{212}At were present which also interfered with the study of the relatively weak ^{214}Fr ground-state transitions. In these earlier studies, the shape of the excitation functions for ^{211}Po(7.45 MeV) and ^{212m}At(7.84, 7.90 MeV) suggested a possible contribution to these groups from the 1- isomer of ^{214}Fr. In the present work, the improved counting rate for the decay of the 1- isomer relative to other peaks in the spectrum has clearly shown a weak group at 7.406 MeV. The 7.406-MeV group has an intensity of 0.3% and populates a level in ^{210}At at 1039 keV. Similarly, an α transition at 7.937 MeV was also clearly discernable on the high-energy side of the 7.90-MeV ^{212m}At group. The 7.937-MeV group populates the 510-keV level of ^{210}At with a branching ratio of 1.0%.

Groups due to ^{214}Fr and ^{212m}At were also observed at an energy of 7.834 MeV in the ^{208}Pb + ^{11}B work reported previously. In this investigation we observed a broad peak at 7.84 MeV which could not be unambiguously resolved into two groups. If this were due to ^{214}Fr ground-state α decay, the energy would correspond to a known level in ^{210}At at 594-keV excitation.[9] However, these data do not warrant a definitive assignment.

We have also assigned a new α transition at 7.605 MeV to the ground-state isomer of ^{214}Fr. This group could not be detected previously because of interference of α radiations from ^{214m}Fr. This transition populates a level in ^{210}At at 836-keV excitation with a relative intensity of 1.0%.

A summary of the results obtained in this study for ^{214}Fr is given in Table I. An α-particle decay scheme based on these results is shown in Fig. 3. For comparison, the decay scheme for the 9- metastable state of ^{214}Fr is also included. While the lower-lying levels of ^{210}At are populated by both isomers, it is interesting to note that for higher excitations, the isomers become much more selective because of the effect of angular momentum in α decay. The fact that the 836- and 1039-keV levels are populated by the low-spin isomer only indicates that these are low-spin states, while the 854-, 971-, and 1231-keV levels probably have spins nearer that of the high-spin isomer of ^{214}Fr.

B. ^{216}Ac

^{216}Ac and its α-decay daughter ^{212}Fr differ from ^{214}Fr and ^{210}At, respectively, by an additional proton pair in the $h_{9/2}$ shell. Rotter *et al.*[17] first observed ^{216}Ac, which has an α-particle energy of 9.14 MeV and 0.39-msec half-life. These results have been extended by Valli and Hyde,[11] who report-

TABLE I. ^{214}Fr ground-state transitions.

This work			Previous results		
E_α (MeV)	Level (keV)	Int. (%)	E_α	Comments	Reference
8.426 ±0.005	0	93.0	8.426		9, 11
8.358 ±0.005	71	4.7	8.363 8.353		9 11
7.937 ±0.008	510	1.0	7.897	^{214}Fr + ^{212m}At	9
(7.84)	594	<0.1	7.834	^{214}Fr + ^{212m}At	9
7.605 ±0.008	836	1.0			
7.406 ±0.008	1039	0.3	7.448	^{214}Fr + ^{211}Po	9

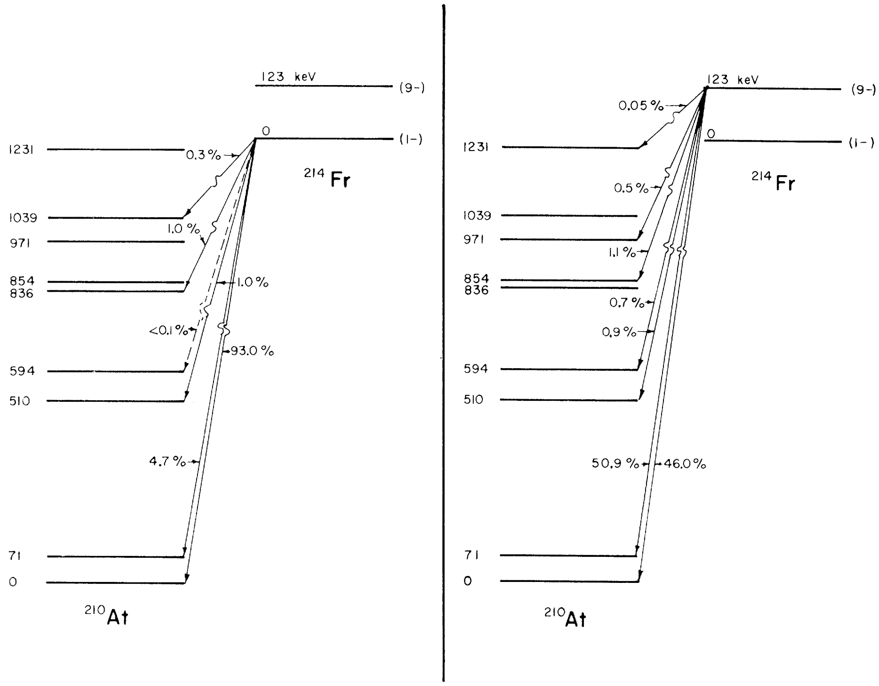

FIG. 3. α-particle decay scheme for the isomers of ^{214}Fr.

ed four α groups belonging to ^{216}Ac produced in bombardments of ^{209}Bi with ^{12}C.

An α-particle spectrum obtained in this investigation for the products of the ^{209}Bi + ^{12}C reaction is shown in Fig. 4. In order to discriminate against the longer-lived ^{214}Fr groups, data accumulation began at the start of the beam burst and continued for 3 msec thereafter. As in the case of ^{214}Fr, α groups of ^{216}Ac were observed to originate from two different states, but the results are markedly different from those obtained by Valli and Hyde.[11]

Metastable-State Transitions

Excitation functions measured for the ^{216}Ac α transitions are shown in Fig. 5. The excitation functions of the two main groups at 9.028 and 9.106 MeV are well characterized and are observed to peak at a ^{12}C energy 12 MeV less than the maximum for ^{215}Ac ($E_\alpha = 7.602$ MeV).[18] The half-life of both these groups was measured to be 0.33 ± 0.02 msec.

Two very weak groups at 8.198 and 8.283 MeV were also observed comprising less than 5% of the total α decay of ^{216}Ac. The relative cross sections for these groups could not be measured at all beam energies, because of interference from the more intense ^{214}Fr groups in the spectrum. However, the shapes of the excitation functions are similar to those of the two main groups at 9.028 and 9.106 MeV.

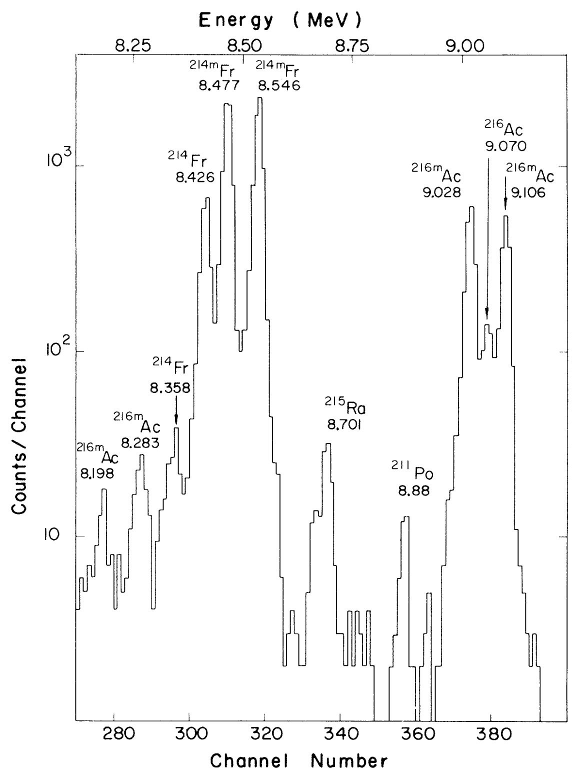

FIG. 4. α-particle spectrum of ^{216}Ac groups produced by irradiation of ^{209}Bi with 84.5-MeV ^{12}C ions.

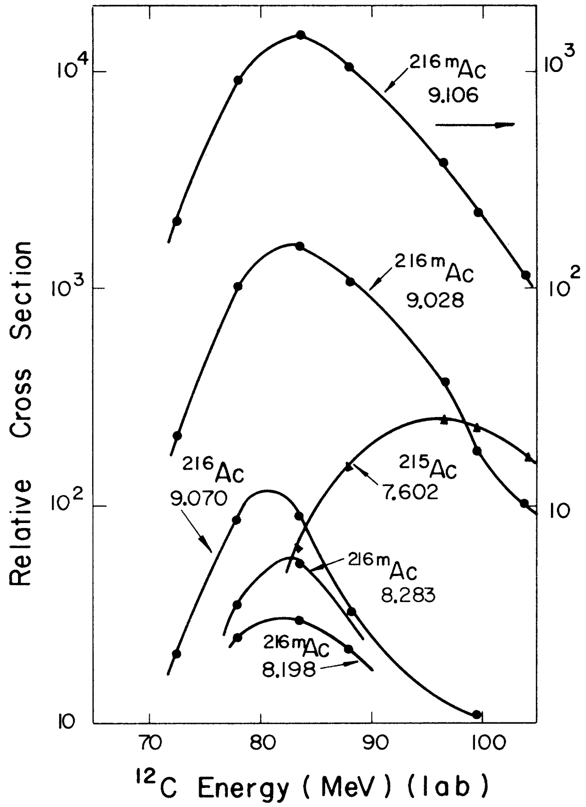

FIG. 5. Excitation functions for the α groups of ^{216}Ac and ^{215}Ac produced in bombardments of ^{209}Bi with ^{12}C.

Ground-State Transitions

The high-energy resolution of the present system has revealed a new α group at 9.070 ± 0.008 MeV that was not observed in the work of Valli and Hyde. We have assigned this group to the ground state of ^{216}Ac. Its excitation function was measured after carefully subtracting the contributions from the two main groups at 9.106 and 9.028 MeV. These results, summarized in Fig. 5, show that the relative cross section for the production of this group is displaced to 3-MeV lower excitation relative to the metastable-state transitions. This is the same effect observed for the low-spin isomers of ^{212}At and ^{214}Fr and is a well-established property of isomer-pair production in heavy-ion compound-nuclear reactions. The half-life of the 9.070-MeV group did not differ from that measured for the two main ^{216}Ac groups within the experimental error.

An additional weak group at 8.99 ± 0.02 MeV also belonging to this decay was observed on the low-energy tail of the 9.028-MeV peak. This group could not be sufficiently resolved over a range of bombarding energies for an excitation-function measurement. Details of the ^{216}Ac α transitions between 8.9 and 9.2 MeV are shown in Fig. 6 for three different ^{12}C energies. On the basis of the α-decay systematics of the metastable-state decays of the previously studied $N=127$ isotones, an α group at 8.99 MeV corresponding to a transition from the ground state of ^{216}Ac was expected. Since no other known α transitions at this energy could result from the products formed in this reaction, the 8.99-MeV group has been assigned to the ground state of ^{216}Ac.

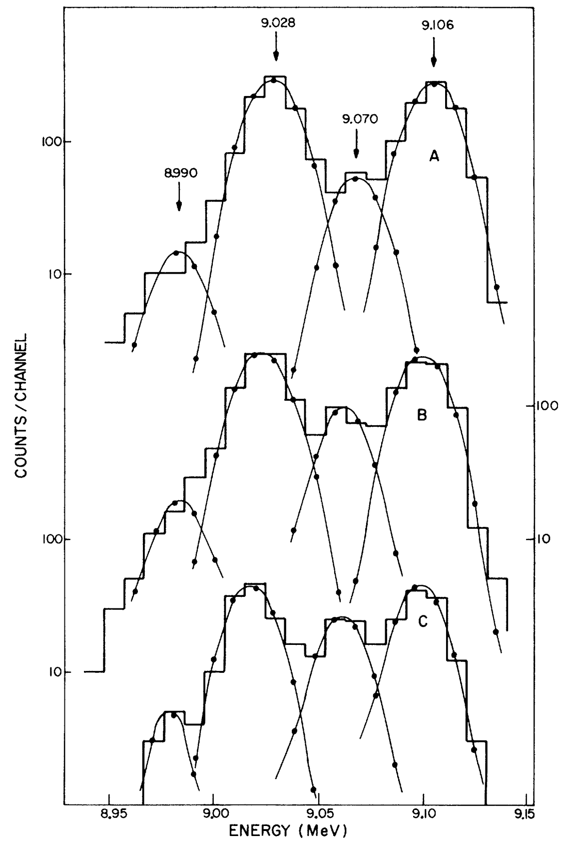

FIG. 6. Detail of the ^{216}Ac groups between 8.9 and 9.2 MeV at three incident ^{12}C energies. The solid line represents the Gaussian line shape calculated from the experimental points. (A) $E_b=88$ MeV. (B) $E_b=78$ MeV. (C) $E_b=72.5$ MeV.

Levels of ^{216}Ac

α-particle transitions observed in this work for ^{216}Ac are compared with the results of Valli and Hyde[11] in Table II. They reported the observation of an isomer pair for ^{216}Ac, but the basis for the assignments relied on an extension of the systematic trend of the excitation energies of the other odd-proton $N=127$ isotones. If this interpretation of the results had been correct, it would have meant that the excitation functions of the isomer pairs of ^{216}Ac would have been identical both in magnitude and in shape. This could be possible,

TABLE II. α groups of ^{216}Ac.

This work				Valli and Hyde	
E_α (MeV)	Level (keV)	Int. (%)	^{216}Ac $J\pi$ assignment	E_α (MeV)	^{216}Ac $J\pi$ assignment
9.106 ±0.005	0	46.2	9−	9.105	9−
9.028 ±0.005	80	49.6	9−	9.020	1−
8.283 ±0.008	839	2.5	9−	8.283	9−
8.198 ±0.008	925	1.7	9−	8.198	1−
9.070 ±0.008	0	90	1−	⋯	⋯
8.99 ±0.02	80	10	1−	⋯	⋯

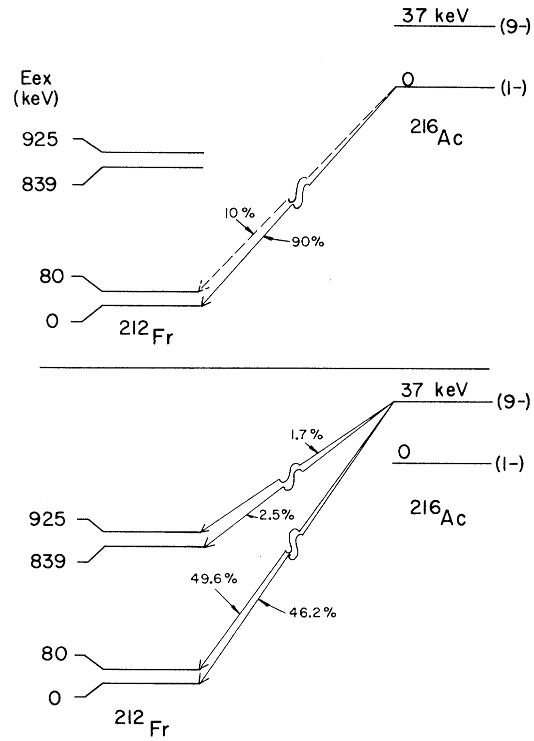

FIG. 7. α-particle decay scheme for the isomers of ^{216}Ac.

particularly in cases where large fission cross sections might lead to considerable spin fractionation of the compound nucleus. The definitive result in the present work which clearly established isomerism in ^{216}Ac was the observation of the 9.070-MeV group and measurement of its excitation-function shift. The low relative cross section and the excitation-function shift characterized this activity as originating from the low-spin member of the ^{216}Ac isomer pair.

Summary of Results on ^{216}Ac

The α decay of ^{216}Ac and the occurrence of α-emitting isomers is similar to that of ^{214}Fr and ^{212}At. The ground state of ^{216}Ac is low spin (probably 1−) and the isomeric state (probably 9−) is at an excitation energy of 37 keV. A decay scheme summarizing the experimental information is presented in Fig. 7.

All the α groups observed by Valli and Hyde for ^{216}Ac which they assigned l to two α-emitting states actually belong to the high-spin member only. In order for them to resolve the weaker α groups from the low-spin isomer, it would have required an improvement in the energy-resolution capabilities of their system.

C. ^{210}At and ^{212}Fr

A comparison of the levels of the $N=125$ isotones ^{208}Bi, ^{210}At, and ^{212}Fr is made in Fig. 8. Included in Fig. 8 is a level scheme for ^{208}Bi that has been calculated by Kim and Rasmussen[1] using a residual neutron-proton tensor component in the shell-model force.

As discussed previously,[9] the levels of ^{210}At tend to cluster into three groups, not unlike the spectrum observed for ^{208}Bi. Although we have observed only four states in ^{212}Fr, they appear to exhibit some of the characteristics observed in ^{208}Bi and ^{210}At. In particular, the effect of the $(3p_{1/2})^{-1}{}_n$ $(1h_{9/2})_p$ single-particle configuration, which gives rise to the 5^+ ground and 4^+ first-excited state in ^{208}Bi, appears to be retained in both ^{210}At and ^{212}Fr. The splitting of the 5^+ and 4^+ states in ^{208}Bi is 64 keV. As proton pairs are added the splitting increases to 71 keV for ^{210}At and to 80 keV for ^{212}Fr.

The details of the multiplets at higher excitation appear to be significantly more complex, and more knowledge of the spins and parities of these levels is required. No information could be obtained on the levels of ^{212}Fr between 0.5–0.7 MeV, because of the presence of other interfering α groups.

Reduced α Widths

In order to calculate reduced α widths,[19] it is necessary to know the spins and parities of the initial and final states. Since we did not obtain this information explicitly, we relied on a comparison with the ^{208}Bi data to estimate the approximate l values for the various α transitions observed in this work. In particular, the trend in the reduced α widths for transitions from the isomer pairs to the ground-state doublet split by the tensor force in the $N=125$ isotones can be studied if the reasonable assumption is made that the transitions are $(9-, 1-) \rightarrow (5+, 4+)$. The calculated α widths for

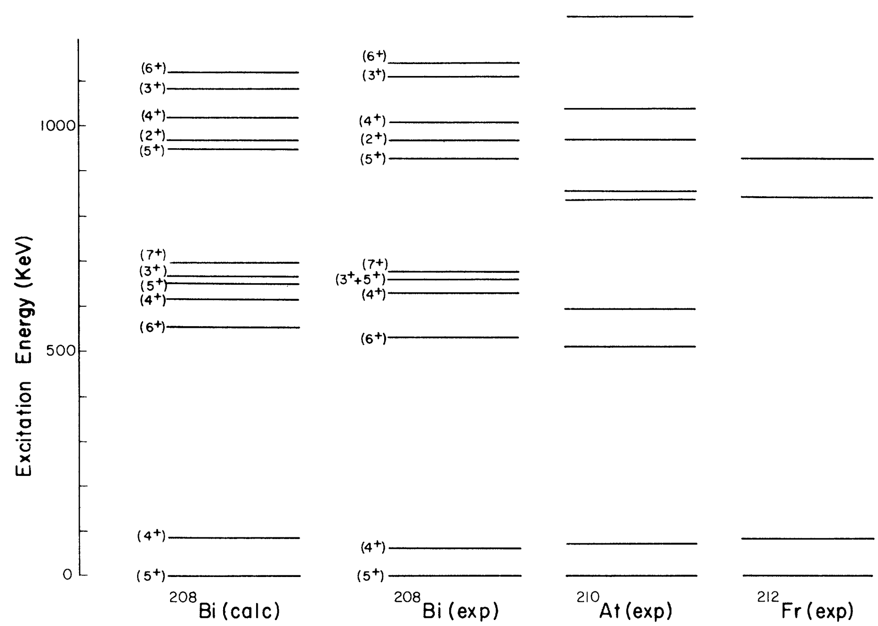

FIG. 8. Energy levels of the odd-proton $N=125$ isotones, ^{208}Bi, ^{210}At, and ^{212}Fr.

transitions to these levels are given in Table III. As expected, the α transitions are all hindered relative to neighboring even-even nuclei in this region which normally have reduced width values >10 keV for nuclei having less than 126 neutrons and >100 keV for nuclei having more than 126 neutrons. In addition, α transitions from the 1− isomer to the 4^+ first excited state are hindered more than a factor of 10 with respect to transitions to the 5^+ ground state in all three cases. The 9− isomers, however, have a slight tendency to favor the 4^+ state. The similar trends in the reduced-width fluctuations of these nuclei indicate that the presence of additional proton pairs does not perturb the α-decay matrix elements for these transitions.

D. ^{215}Ra

This nuclide was first reported by Griffioen and Macfarlane[20] to have an α-decay energy of 8.7 MeV and a half-life of 1.6 msec. Subsequent studies of ^{215}Ra confirmed these results.[17,18] With the improved capabilities of our experimental system, this nuclide was re-examined in order to obtain more detailed information on its decay. During the course of this work, new results were reported by Valli and Hyde[11] using essentially the same method. Our results, which are in agreement with their findings are summarized below.

An α-particle spectrum (covering the range of 7–9 MeV) of the products resulting from the bombardment of ^{209}Bi with 68-MeV (lab) ^{11}B ions is shown in Fig. 9. In addition to Ra groups, α particles due to Po, At, Rn, and Fr were observed in the spectrum. Most of these nuclides were produced via direct-reaction mechanisms or charged-particle emission from the compound nucleus. The ^{213}Rn group at 8.090 MeV,[20] however, was produced as the α-decay daughter of ^{217}Ra, which decayed before reaching the detector.[21,22]

^{215}Ra α Transitions

At ^{11}B bombarding energies between 60 and 90 MeV (lab), three α groups at 8.701, 8.175, and 7.885 MeV are observed, which we have assigned to ^{215}Ra. Relative excitation functions of these activities and of ^{214}Ra (7.136 MeV)[23] have been mea-

TABLE III. Reduced α widths in keV for α transitions to the ground and first excited states of the odd-proton $N=125$ isotones.

Predicted daughter $J\pi$	1− isomer ^{212}At (Ref. a)	^{214}Fr	^{216}Ac	9− isomer ^{212}At (Ref. a)	^{214}Fr (Ref. b)	^{216}Ac
5+	10	5.2	6.4	2.1	1.8	2.5
4+	0.8	0.1	0.3	7.3	3.1	4.3

[a]Calculated from the data of Ref. 8. [b]Taken from Ref. 9.

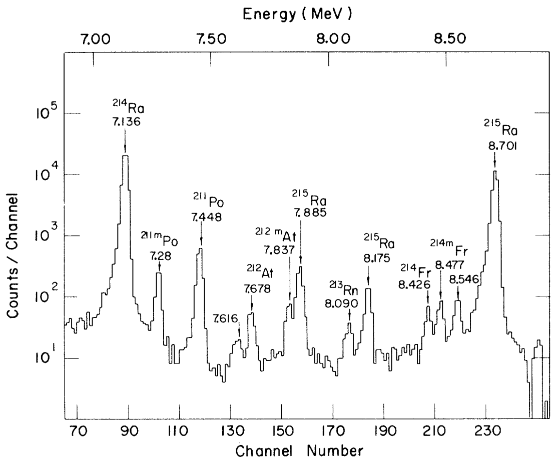

FIG. 9. α-particle spectrum for products of the $^{209}Bi + ^{11}B$ reaction at an incident energy of 63 MeV.

sured and are shown in Fig. 10. The relative cross sections for formation of the ^{215}Ra groups peaked at an excitation energy 11 MeV lower than ^{214}Ra, which was consistent with their assignment of being products of a (^{11}B, 5n) reaction. The half-life of ^{215}Ra was measured to be 1.56 ± 0.10 msec.

The results from this work are compared with the data of Valli and Hyde in Table IV. The two sets of data are generally in agreement with only minor differences in the α-energy determinations. Our counting statistics were generally better than what they had obtained.

Levels of ^{211}Rn

The ^{211}Rn states populated from the α decay of ^{215}Ra are shown in Fig. 11. These are compared with the first three levels in ^{207}Pb. The similarity between the levels of ^{207}Pb and ^{211}Rn suggests that the lowest states of ^{211}Rn retain a significant amount of single-particle character. It appears that adding four protons to ^{207}Pb depresses the energy spacings to lower values. This might be a consequence of core polarization.

The transition to the ground state of ^{211}Rn accounts for 96% of the total α decay of ^{215}Ra. The large branching ratio is due to the effect of the energy dependence on α-decay rates, since the single-particle level spacings are relatively large in this region. The branching to the 0.83-MeV level, however, is 2.6% compared with the 1.4% branching to the 0.54-MeV state. Thus, the transition to the 0.54-MeV level is relatively hindered, since $l = 3$ α waves are probably involved in both cases.

TABLE IV. α groups of ^{215}Ra.

This work E_α (MeV)	Int (%)	Valli and Hyde E_α (MeV)
8.701 ± 0.005	96.0	8.698 ± 0.005
8.175 ± 0.008	1.4	8.168 ± 0.008
7.885 ± 0.008	2.6	7.880 ± 0.008

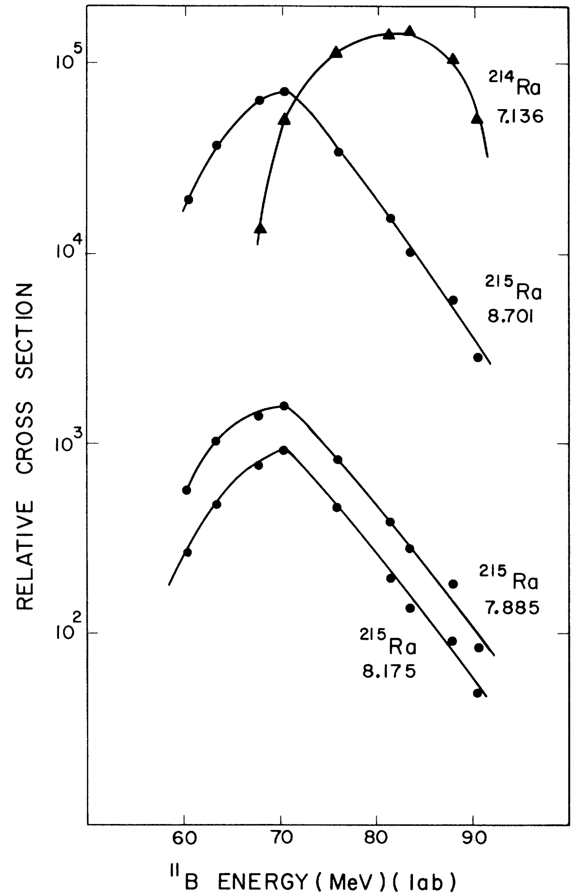

FIG. 10. Excitation functions for the α groups of ^{215}Ra and ^{214}Ra produced in bombardments of ^{209}Bi with ^{11}B.

Reduced α Widths

Experimental α-particle reduced widths[19] have been calculated for the observed transitions using

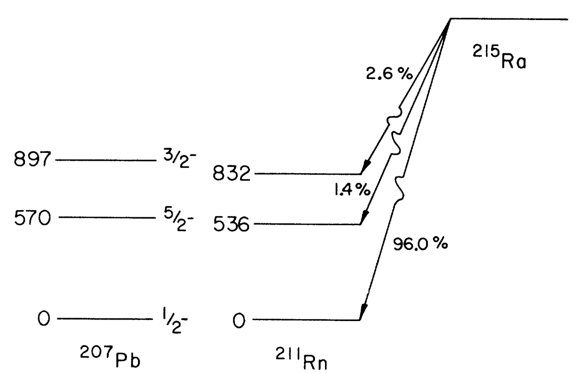

FIG. 11. α-particle decay scheme for ^{215}Ra.

TABLE V. Reduced α widths and intensities for ^{215}Ra.

^{211}Rn level (keV)	Probable neutron-hole state	δ^2 (keV)	l	$10^2 \times P/P_{g.s.}$	$\gamma^2/\gamma^2_{g.s.}$	Int. theor.	Int. expt.
0	$3p_{1/2}$	6.9	5	100	1.00	100	100
536	$2f_{5/2}$	0.63	3	15.9	0.08	1.3	
			5	3.56	0.30	1.1	
			7	0.43	1.26	0.5	
						...	
						2.9	1.5
832	$3p_{3/2}$	8.6	3	2.20	1.19	2.6	
			5	0.49	0.66	0.3	
						...	
						2.9	2.7

spin and parity values for the levels of ^{211}Rn in analogy with those of ^{207}Pb. For these calculations, it was assumed that the ground state of ^{215}Ra was $\frac{9}{2}+$ as predicted by the shell model. The experimental reduced-width values δ^2 are given in Table V. The reduced width for the ground-state-to-ground-state decay of ^{215}Ra is hindered a factor of 20 with respect to neighboring even-even nuclei having >126 neutrons. The reduced width for the transition to the 0.54-MeV level is smaller by a factor of ~10 with respect to the other two transitions.

We have made an attempt to compare these reduced widths with theoretical values derived from a shell-model calculation. Because of the apparent similarity of the states of ^{211}Rn and ^{207}Pb, we have assumed pure shell-model states in the calculation of the reduced widths in the decay of ^{215}Ra. We have used the "δ-function" approximation in the shell-model calculation of α-particle reduced widths to simplify the calculation.[24] Reduced widths were calculated relative to the strength of the ground-state transition. For ^{215}Ra we assumed that α-decay matrix elements involve one of the three sets of paired protons from the $1h_{9/2}$ shell. Since only ratios have been calculated, the proton factors cancel out. Therefore, the ratios depend on one of the final-state neutron-hole orbitals for which we use Blomqvist and Wahlborn[25] wave functions.

The results of these calculations are summarized in Table V. Relative penetrability factors, shown in column 5, have also been calculated and are multiplied by the relative reduced widths $\gamma^2/\gamma^2_{g.s.}$ to yield theoretical intensities for each α l wave. The contribution from each l wave is then summed and compared with the experimental value in column 8. Most of the reduction in the α intensities to the first and second excited states is due to barrier-penetrability effects. The shell-model calculation predicts an additional retardation for the transition to the $2f_{5/2}$ state which we have assigned to the first excited state. The experimental evidence is clearly consistent with this prediction. The decay to the second excited state is predicted to be retarded relative to the ground-state transition only by the barrier-penetrability-factor difference. This, again, is consistent with the experimental observation.

In conclusion, it appears that the application of the simple shell-model calculation of α-particle reduced widths in the decay of ^{215}Ra can properly account for the observed relative transition strengths to the low-lying states of ^{211}Rn.

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Photoneutron Cross Sections for Ba^{138} and N^{14}†

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Photoneutron cross sections, including $\sigma[(\gamma,n)+(\gamma,pn)]$, $\sigma(\gamma,2n)$, and $\sigma(\gamma,3n)$ for Ba^{138} and $\sigma[(\gamma,n)+(\gamma,pn)]$ for N^{14}, were measured with monoenergetic photons from threshold to 29 MeV. The partial cross sections were determined by neutron multiplicity counting, and the average neutron energies for both single- and double-photoneutron events were determined simultaneously with the cross-section data by the ring-ratio technique. The N^{14} data, when combined with data from other laboratories, appears to show that the (γ,pn) process dominates the decay of the giant resonance in this nucleus. The giant-resonance parameters for Ba^{138} are nearly the same as those for Pr^{141}, which has the same (magic) neutron number.

INTRODUCTION

Photoneutron cross sections for Ba^{138} and N^{14} were measured as part of a continuing survey to examine the influence of the characteristics of nuclei on the giant resonance. One of the key elements in the survey is $_{56}Ba^{138}$ which has a closed neutron shell ($N=82$) and which differs from $_{59}Pr^{141}$ (measured previously at this laboratory[1]) by three protons. The question to be resolved is whether the giant-resonance parameters for these two nuclei are the same, since the giant-resonance decay is dominated by neutron emission.

The Ba^{138} sample was in the form of $Ba(NO_3)_2$. It therefore was necessary to measure first the photoneutron cross section for N^{14} in order to obtain the Ba^{138} cross section. (The oxygen contribution was determined from previous measurements.[2,3]) Although the N^{14} nucleus is interesting in its own right (it is self-conjugate, odd-odd, and light), its photoexcitation and subsequent decay are very complex, involve several reaction channels, and require a much more comprehensive study than was done in the present experiment. The present contribution, however, determines several quantities of interest vital to that study, and gives an over-all view of the N^{14} giant resonance.

Some work has been done previously on N^{14}, albeit with continuous bremsstrahlung sources, including a $N^{14}(\gamma,n)$ activation measurement by King, Haslam, and Parsons,[4] a $N^{14}[(\gamma,n)+(\gamma,pn)+2(\gamma 2n)]$ yield measurement by Fast *et al.*,[5] a $N^{14}(\gamma$, charged particle) cloud-chamber experiment by Komar, Krzhemenek, and Yavor,[6] a $N^{14}(\gamma,p)$ spectrum measurement by Kosiek, Maier, and Schlüpmann,[7]