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HIGH-SPIN NEUTRON HOLE EXCITATIONS IN LIGHT ODD-A Pb NUCLEI*

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Abstract: The high-spin level structures of $^{195, 197, 199, 201, 203}Pb$ have been investigated by $(\alpha,xn\gamma)$ and $(^{3}He,xn\gamma)$ spectroscopy. The resulting level spectra are interpreted in terms of the weak coupling of an $\nu i_{13/2}$ hole to known states of the even-A core nuclei.

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In odd mass Pb nuclei with $A < 205$, $13/2^{+}$ isomers of $\nu i_{13/2}^{-1}$ character are well established, and some low-spin levels are known from radioactivity studies[1]. However, nothing has been known up to now about the high-spin level structures of these semi-magic nuclei. In marked contrast, high-spin levels in the even-A Pb nuclei down to A=194 have been studied in detail by two groups [2,3], and the results have been interpreted in terms of neutron hole excitations. We have investigated the five odd-A Pb nuclei in the mass range A=195-203 by in-beam γ-ray spectroscopy. The main results are reported briefly here, with most emphasis on systematic features of the high-spin level spectra.

The experiments were performed at the Michigan State University cyclotron by means of $(\alpha,3n\gamma)$ and $(^{3}He,xn\gamma)$ reactions on isotopically enriched HgO targets. Strong yrast cascades terminating in the known $\nu i_{13/2}^{-1}$ isomeric states were observed in all five nuclei. Isotopic identifications were based on excitation function measurements and on the requirement of approximate intensity balance, at all bombarding energies, between the transitions populating and depopulating the $13/2^{+}$ isomers. The experiments included γ-ray singles, comprehensive (γ-γ-t) coincidence measurements, and γ-ray angular distribution determinations. In addition, lifetime measurements spanning a range from 2 ns to many seconds were performed, and many new isomers in the odd-A Pb nuclei were identified.

The principal results of the investigations are summarized in the partial level schemes shown in Fig. 1, which also includes the even-A Pb level spectra [2,3].

The nucleus ^{203}Pb: A pulsed beam $^{202}Hg(\alpha,3n\gamma)$ experiment revealed a ^{203}Pb isomer with $t_{1/2}$ = 0.48±0.04 s, and subsequent γ-γ coincidence and prompt angular distribution measurements firmly established the complete isomeric decay scheme. The 0.5 s isomeric state is placed at 2949 keV and assigned $J^{\pi} = 29/2^-$. It decays by 153 keV E3 and 1027 keV M4 transitions to $23/2^+$ and $21/2^+$ levels, which de-excite in turn by several cascades leading to the known 6.2 s $13/2^+$ isomer at 825 keV. The dominant neutron hole configuration $f_{5/2}^{-1}, i_{13/2}^{-2}$ is clearly indicated for the $29/2^-$ state in ^{203}Pb, which can be ascribed to the coupling of the ^{204}Pb 9^- state (Fig. 1) with the additional $\nu i_{13/2}$ hole.

The 0.5 s ^{203m}Pb activity has also been observed recently by Linden et al.[4].

The nuclei ^{201}Pb and ^{199}Pb: These nuclei have been investigated by $(\alpha,3n\gamma)$ reactions on ^{200}Hg and ^{198}Hg targets. As illustrated in Fig. 1, three new isomers have been identified in each nucleus. The data showed clearly that the 0.54 μs and 10.6 μs isomers in ^{201}Pb and ^{199}Pb, respectively, de-excite to the $25/2^-$ levels in these nuclei, but the connecting transitions were not observed even in the delayed γ-ray spectra. If, as the level systematics suggest, these transitions are of E2 character, their energies must be less than 80 keV.

The nuclei ^{197}Pb and ^{195}Pb: These nuclei have been studied by $(^3He,4n\gamma)$ and $(^3He,6n\gamma)$ reactions on a ^{198}Hg target. The measurements established a ^{197}Pb level spectrum which is qualitatively very similar to the ^{199}Pb and ^{201}Pb spectra, but the $21/2^-$ level in ^{197}Pb occurs at such a low energy that it has the rather long half-life of 1.5±0.1 μs. In the case of ^{195}Pb, our data were

of poorer quality than for the other nuclei studied. Nevertheless, we have established quite definitely that the $t_{1/2}$ = 10 μs isomer previously attributed [3] to ^{194}Pb should be reassigned to ^{195}Pb. It appears that strong 970 and 581 keV γ-rays, which decay with the 10 μs half-life, must earlier[3] have been mistaken for the known [2] 966 and 575 keV γ-rays of ^{194}Pb. The spin-parity assignments proposed for the ^{195}Pb levels (Fig. 1) are based solely on systematic trends, since the transition multipolarities have not been determined.

The outstanding feature of the results is the remarkably close correspondence between the odd-A and even-A levels observed over the entire range of nuclei studied. It appears that the odd-A level spectra can be understood in terms of the coupling of known states of the even-A core nuclei with an additional $i_{13/2}$ neutron hole. The closely spaced $17/2^+$, $15/2^+$ and $19/2^+$, $21/2^+$ doublets in ^{201}Pb, ^{199}Pb and ^{197}Pb are clearly marked as members of hole-core coupling multiplets associated with the 2_1^+ and 4_1^+ core states, and in ^{203}Pb members of three even parity multiplets have been identified. The observed multiplet splitting is very small,indicating that a weak coupling description may be a rather good approximation. It is not surprising that the lower-spin multiplet members were not observable with the experimental methods employed here; we note, however, that in a recent radioactivity study [5], $9/2^+$ and $11/2^+$ levels of probable $\nu i_{13/2} \otimes 2^+$ parentage were located just below the $17/2^+$ level in ^{203}Pb. A hole-core coupling interpretation for the negative parity levels also is strongly indicated by the energy systematics. In view of the two-neutron hole structures proposed for the 5^-, 7^- and 9^- states in the even-A nuclei [2,3], the probable dominant active components in the intrinsic structures of the $21/2^-$, $25/2^-$ and $29/2^-$ states are:

$21/2^-$	:	$\nu i_{13/2}^{-2}, \nu p_{3/2}^{-1}$
$25/2^-$	:	$\nu i_{13/2}^{-2}, \nu p_{1/2}^{-1} + \nu i_{13/2}^{-2}, \nu p_{3/2}^{-1}$
$29/2^-$	:	$\nu i_{13/2}^{-2}, \nu f_{5/2}^{-1}$

The observed electromagnetic properties also point towards a weak coupling scheme. A comparison of the B(E1) and B(E2) values extracted from the many measured half-lives shows generally close agreement between the transition probabilities for corresponding transitions in adjacent odd-A and even-A nuclei. The one notable exception is the 258 keV $21/2^+ \rightarrow 17/2^+$ transition in ^{203}Pb, which is considerably faster than the retarded $4_1^+ \rightarrow 2_1^+$ ^{204}Pb transition. In addition, we should note the general occurrence of sizable M1 admixtures in the $15/2^+ \rightarrow 13/2^+$ and $19/2^+ \rightarrow 17/2^+$ transitions between multiplets. These deviations from strict weak coupling predictions can probably be attributed to non-diagonal interaction components, which give rise to some configuration mixing between states of $i_{13/2} \otimes 0^+$, $i_{13/2} \otimes 2^+$ and $i_{13/2} \otimes 4^+$ character. In other respects, the weak coupling scheme accounts rather satisfactorily for the main features and the systematic trends of the odd-A Pb spectra, although more ambitious theoretical treatments of microscopic nature might well yield additional structural insights.

In conclusion, it is interesting to contrast the high-spin odd-A Pb spectra with the distinctively different types of $\nu i_{13/2}$ level spectra characterizing prolate, oblate and triaxial nuclei in the A=150-200 range. The strong influence of the closed proton shell in stabilizing the spherical nuclear shape, even when there are as many as thirteen vacancies in the N=6 neutron shell, is reflected by the absence of any trace of rotational structure in the Pb spectra, and the near-degeneracy of the core-hole multiplet members indicates very small quadrupole moments. With the removal of protons from the

closed shell and the accompanying increase in quadrupole moments, the interaction of the $i_{13/2}$ hole with the core increases the multiplet splittings until decoupled or strong coupled level structures, characteristic of the shape of the core, develop.

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References

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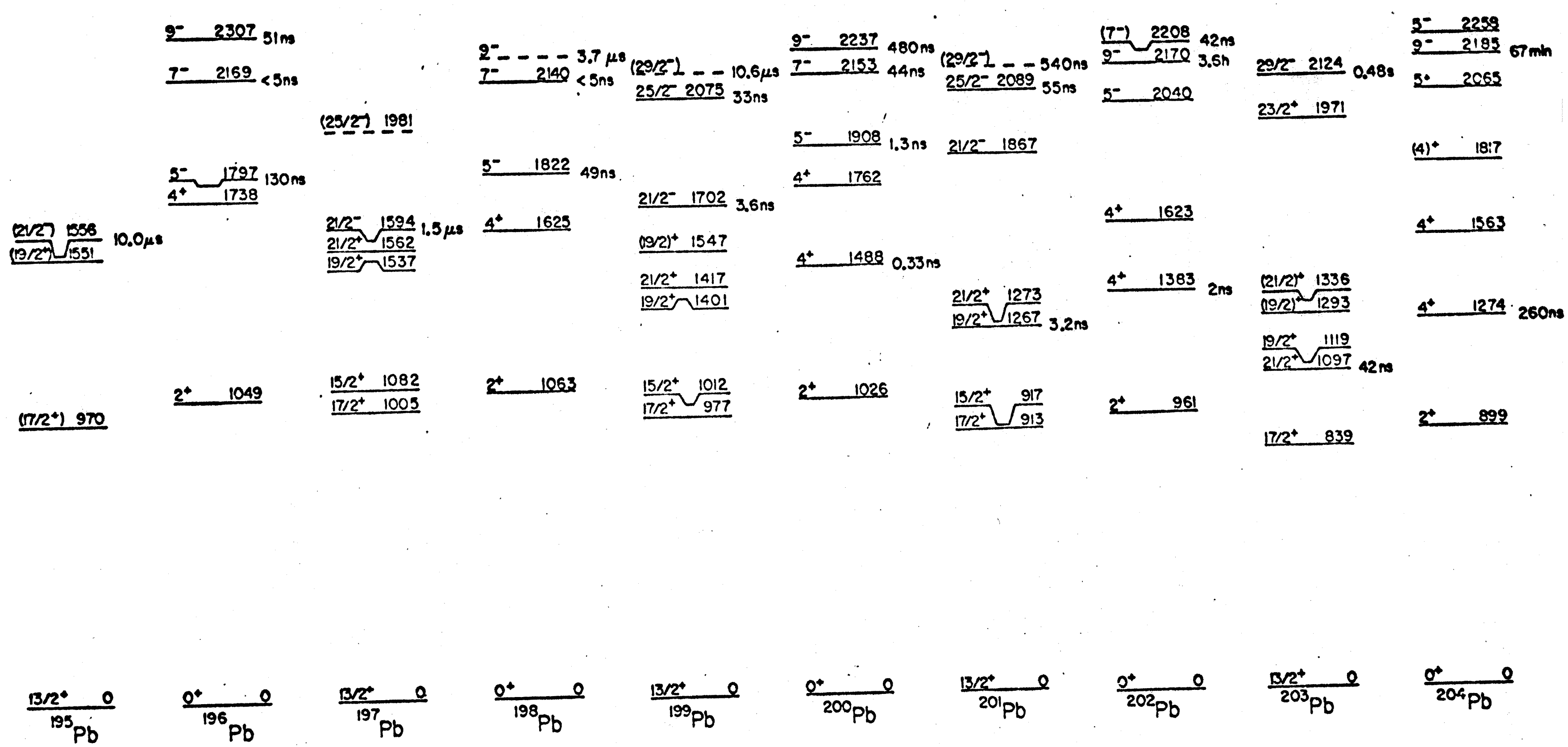
Figure Caption

Fig. 1. High-spin level systematics for the A=195-204 Pb isotopes. Data for the even A nuclei are from the literature [2,3], and for the odd-A nuclei from the present work. Excitation energies in the odd-A level schemes are expressed relative to zero energy for the $13/2^+$ isomers.


195Pb
13/2+ 0
(17/2+) 970
(21/2-) 1556
(19/2+) 1551 10.0μs
196Pb
0+ 0
2+ 1049
4+ 1738
5- 1797 130ns
7- 2169 <5ns
9- 2307 51ns
197Pb
13/2+ 0
17/2+ 1005
15/2+ 1082
19/2+ 1537
21/2+ 1562
21/2- 1594 1.5μs
(25/2-) 1981
198Pb
0+ 0
2+ 1063
4+ 1625
5- 1822 49ns
7- 2140 <5ns
9- 3.7μs
199Pb
13/2+ 0
17/2+ 977
15/2+ 1012
19/2+ 1401
21/2+ 1417
(19/2)+ 1547
21/2- 1702 3.6ns
25/2- 2075 33ns
(29/2-) 10.6μs
200Pb
0+ 0
2+ 1026
4+ 1488 0.33ns
4+ 1762
5- 1908 1.3ns
7- 2153 44ns
9- 2237 480ns
201Pb
13/2+ 0
17/2+ 913
15/2+ 917
19/2+ 1267 3.2ns
21/2+ 1273
21/2- 1867
25/2- 2089 55ns
(29/2-) 540ns
202Pb
0+ 0
2+ 961
4+ 1383 2ns
4+ 1623
5- 2040
9- 2170 3.6h
(7-) 2208 42ns
203Pb
13/2+ 0
17/2+ 839
21/2+ 1097 42ns
19/2+ 1119
(19/2) 1293
(21/2)+ 1336
23/2+ 1971
29/2- 2124 0.48s
204Pb
0+ 0
2+ 899
4+ 1274 260ns
4+ 1563
(4)+ 1817
5+ 2065
9- 2185 67min
5- 2259