Title
A HIGH-SPIN ISOMER IN 211At

Permalink
https://escholarship.org/uc/item/4zh1c60k

Authors
Maier, K.H.
Leigh, J.R.
Puhlhofer, P.
et al.

Publication Date
1971-05-01

Submitted to
Physics Letters

UCRL-20481
Preprint

C.2

A HIGH-SPIN ISOMER IN ^{211}At

K. H. Maier, J. R. Leigh, F. Pühlhofer, and R. M. Diamond

May 1971

AEC Contract No. W-7405-eng-48

LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

UCRL-20481 c.2

DISCLAIMER

A HIGH-SPIN ISOMER IN ^{211}At *

K. H. Maier†, J. R. Leigh, F. Pühlhofer††, and R. M. Diamond

Lawrence Radiation Laboratory
University of California
Berkeley, California 94720

May 1971

A 4 μsec isomer has been observed in ^{211}At at an excitation energy of 4.816 MeV. The multipolarities of the de-excitation γ-rays suggest a very high spin. The excitation energy, g-factor and the strongly enhanced E3 decay may be described by a 4p-1h configuration with $I^{\pi} = 39/2^{-}$.

- - -

In a recent study of several N = 126 isotones [1] an isomer of half-life 4.2 ± 0.4 μsec was observed in ^{211}At; it has the following very interesting properties: 1) the isomer lies at an excitation energy of 4.816 MeV, 2) it has very high angular momentum, I ≈ 39/2, 3) it decays essentially by a single cascade sequence of 9 γ-rays, only one branching being observed, and 4) the isomeric transition has E3 multipolarity and shows considerable enhancement over the single-particle estimate.

^{211}At has been populated following (heavy ion, xn) reactions using beams of ^{4}He, ^{7}Li and ^{11}B from the Berkeley Hilac incident on targets of ^{209}Bi, ^{208}Pb and ^{204}Hg, respectively. The 5 msec Hilac beam pulse (repeated 36 times per sec) was chopped with an electrostatic deflector system to give microsecond

---

*Work performed under the auspices of the U. S. Atomic Energy Commission.

†Present address: Hahn-Meitner-Institut, Berlin.

††On leave from Physikalisches Institut der Universität, Marburg, Germany.

beam pulses with variable repeat intervals. Ge(Li) gamma-ray spectra have been recorded both in-beam and in the intervals between the microsecond pulses. Excitation functions, both delayed and in-beam, were obtained with the ^{4}He and ^{7}Li beams. In both cases the isomer yield peaked 8 to 10 MeV higher than the prompt component, indicating the high angular momentum of the state. A solenoidal spectrometer with a cooled Si detector was used to record conversion-electron spectra both delayed and in-beam. The half-life of the isomer has been determined by recording Ge(Li) γ-ray spectra obtained in four successive time intervals of 4 μsec each. In-beam angular distributions were performed to obtain A_2's for the transitions with a strong prompt component. The g-factor of the 4 μsec states was measured using a pulsed-beam time-differential method, the nuclear alignment being preserved by use of a liquid ^{204}Hg target. The data are summarized in table 1.

A PDP-7 on-line computer system was used to record all γ-γ coincidence events associated with the isomeric decay. The coincidences establish that the transitions form essentially a single cascade and reveal two other isomeric states in the decay chain with half-lives of the order of 50 nsec. These delays, along with measurements of the prompt to delayed intensity ratios of the γ-rays, establish the time ordering of the transitions. The level scheme shown in fig. 1 is thus established. Our data do not determine the 25 - 689 keV sequence, but a recently published study on this same nucleus has done so [2]. In-beam, the 203 keV line shows slight broadening and, in fact, has a contribution from a prompt γ-ray of approximately the same energy. Corrections for this have been made in evaluating the ratios presented in columns 12 and 13 of the table. These ratios for the 203 keV and 1536 keV are equal and do not, therefore, conclusively indicate their time ordering. However, the fact that they are equal indicates strongly that they arise from states of approximately equal energy and not from states 1.5 MeV apart as the reverse ordering would suggest. The large increase in the ratio for the lower states supports this argument. The conversion-electron data on the 511.2 keV transition rule out the possibility of its being due to positron annihilation.

The angular distribution and conversion-electron data establish the multipolarities indicated in column 11 of table 1. Thus, the spins of states up to the $23/2^-$ level at 1928 keV can be assigned with confidence. In making the spin assignments we have assumed that the angular momentum of the observed states increases monotonically with energy. This assumption is supported by the excitation function data and the single-cascade decay mode of the isomer. The delay associated with the 713 keV transition favors the E3 assignment and this is supported by the model-dependent arguments presented below. The only transition whose multipolarity cannot be assigned is the 1536 keV gamma-ray. The γ-γ coincidence work indicates that the half-life of the 4177 keV state is $\leq$ 10 nsec. This implies a dipole or quadrupole transition (magnetic or electric), but an enhanced E3 transition cannot be ruled out. It is probable, however, that the isomer spin is restricted to $(39/2, 41/2)^{\pm}$.

A shell-model calculation has been performed in order to obtain information about the structure of the observed states. The configuration space included all three-particle states in the h 9/2, f 7/2, and i 13/2 orbitals outside the ^{208}Pb core. A central force, with parameters determined by Glendenning and Harada [3] for ^{210}Po, has been used as the residual interaction. Several diagonal two-particle matrix elements have been modified in order to get better agreement with the experimental level scheme of ^{210}Po [4,5]. This procedure can be justified when the configuration mixing is very small and so has only a minor influence on the energy. For ^{211}At we get very good agreement not only for the yrast states shown in fig. 1, but also for other experimentally known states [5,6]. This is in agreement with similar calculations of refs. 2 and 6.

The calculations accurately reproduce all states in ^{211}At up to the $23/2^-$ state and suggest strongly a change in parity above this because the only calculated negative parity states with $J > 23/2$ lie above 4 MeV. Therefore, we assign the spins $25/2^+$ and $29/2^+$ to the levels at 2617 keV and 2641 keV. This implies the multipolarities E1 and E3 for the 689 keV and 713 keV transitions. The branching ratio and lifetime support these assignments.

The 1.5 MeV gap above the 2641 keV level is indicated by the calculation and it is very tempting to assign the 4177 keV state as $33/2^-$. However, the maximum spin obtainable for a 3-proton configuration is 33/2. The isomeric state, at least, has a spin greater than this and cannot, therefore, be described by a simple 3-particle configuration. It is easy to estimate that this is just the excitation at which high spin ($J \geqslant 31/2$) 4 particle-1 hole states may occur. Therefore, we calculated the energies of the yrast levels of the 4p-1h configuration assuming that they consist of:

a) 3 protons with the configuration, and energy, of the lower yrast levels of ^{211}At,

b) one neutron in the four lowest single-particle states of ^{209}Pb, and

c) one neutron hole in the four lowest hole states of ^{207}Pb.

The diagonal matrix elements of the proton-neutron, proton-neutron hole and neutron-neutron hole interactions have been calculated using information from the experimental level schemes of ^{210}Bi, ^{208}Bi and ^{208}Pb. The mixing between the 4p-1h states has been neglected, as well as collective p-h states. A weak coupling calculation showed that states based on the 3^- state of ^{208}Pb certainly do not belong to the yrast band. Because of the approximations made the calculation of the 4p-1h states is considerably less accurate than the three-particle calculation described above. However, possible candidates for the observed states above 4 MeV are suggested, namely:

$$(\pi h_{9/2}{}^{3})_{21/2^-} \cdot (\nu g_{9/2}\, p_{1/2}{}^{-1}) = 31/2^+$$

$$(\pi h_{9/2}{}^{2}\, f_{7/2})_{23/2^-} \cdot (\nu g_{9/2}\, p_{1/2}{}^{-1}) = 33/2^+$$

$$(\pi h_{9/2}{}^{2}\, i_{13/2})_{29/2^+} \cdot (\nu g_{9/2}\, p_{1/2}{}^{-1}) = 39/2^-$$

with calculated energies as shown in fig. 1. The observed E3 transitions $39/2^- \rightarrow 33/2^+$ and $29/2^+ \rightarrow 23/2^-$ take place between states differing only by a single particle, the transition in both cases being i 13/2 → f 7/2.

Bergström, et al. [2] have observed the $29/2^+$ state as a 70 nsec isomer following the ^{209}Bi(α,2n)^{211}At reaction. The deduced level schemes are identical below the $29/2^+$ level and the more accurate half-lives measured in ref. 2 are indicated in fig. 1 for the $21/2^-$ and $29/2^+$ states.

Our measured branching ratio for the $29/2^+$ state gives the reduced transition probability for the 713 keV transition ($T_{1/2}(\gamma)$ = 325 nsec), B(E3, 713 keV) = 40,000 ± 10,000 e^2 fm^6. This value is eight times larger than the theoretical estimate for the transition between the $(h\ 9/2)^2$ i 13/2 and $(h\ 9/2)^2$ f 7/2 configurations. This is in agreement with the value

51,000 ± 7000 e^2 fm^6 found in ref. 2 and the enhancement has been described there in terms of admixtures of the 3^- octupole state of the ^{208}Pb core to these three-particle states.

From the measured half-life of the 4816 keV state we obtain B(E3, 435 keV) = 83,000 ± 9000 e^2 fm^6 and this is comparable to the transition rate for the 3^- state of ^{208}Pb ($T_{1/2}$ = 17 psec [7]), B(E3, 3^-) = 86,000 e^2 fm^6. Admixtures of the 3^- core-excited state to the proposed configurations, similar to those of the $29/2^+$ and $23/2^-$ levels [2] may be expected. The particle-phonon coupling matrix element necessary to describe the enhancement is then

$$\left\langle (i\ 13/2,\ 3^-)7/2 \middle| H_{coupl} \middle| f\ 7/2 \right\rangle \approx 1.3\ \text{MeV}$$

and may be compared with 0.9 MeV [2] for the 713 keV transition in this same nucleus, and the theoretical estimate of 1.34 MeV [8]. The reason for the difference in the two experimental values is not understood.

The g-factor of the isomeric state was measured as 0.72 ± 0.07. This is in reasonable agreement with the value 0.77 obtained for the suggested configuration, including the core coupling effects. This will be discussed further in ref. 1. The measured properties of the states above 4 MeV may, therefore, be described by the assigned configurations indicated in fig. 1, with the inclusion of admixtures of the 3^- core excited state. We feel, therefore, that the $39/2^-$ assignment for this isomer is probable.

We would like to thank Dr. N. K. Glendenning for providing the two-particle matrix elements used in our calculations. F. Pühlhofer acknowledges a grant from the Bundesministerium für Bildung und Wissenschaft in Bonn and K. H. Maier greatly appreciated the support of a NATO fellowship during his stay at the Lawrence Radiation Laboratory.

References

1. K. H. Maier, J. R. Leigh, R. M. Diamond, to be published.

2. I. Bergström, B. Fant, C. J. Herrlander, K. Wikström and J. Blomqvist, Physica Scripta 1 (1970) 243.

3. N. K. Glendenning and K. Harada, Nucl. Phys. 72 (1965) 481.

4. L. J. Jardine and S. G. Prussin, to be published.

5. I. Bergström et al., Annual Report, Research Institute for Physics, Stockholm (1970).

6. I. Bergström, B. Fant, C. J. Herrlander, P. Thieberger and K. Wikström, Phys. Letters 33B (1970) 476.

7. A. R. Barnett and W. R. Phillips, Phys. Rev. 186 (1969) 1205; value adopted in Nuclear Data Sheets, Vol. 5, No. 5 (1971).

8. B. R. Mottelson, Proc. Int. Conf. Nucl. Structure, Tokyo (1967).

Table 1

Electron conversion and angular distribution coefficients for transitions in ^{211}At.

E_γ	I_γ	α_K		α_L		α_M		A_2		Multi-polar-ity	$I_\gamma$total/$I_\gamma$isomer[a]	
		exp	theory	exp	theory	exp	theory	exp	theory		34 MeV α	41 MeV ^7Li
1067.1±0.5	109 ±11	.004 ±.002	E1 .002 E2 .005					+0.22 ±0.04	E2 +0.44 M1 -0.31	E2	7.6±0.6	7.5±0.8
253.5±0.5	82[b]	.08 ±.02	E2 .10 M1 .74	0.092[c]	E2 .092	0.026 ±0.005	E2 0.03 M1 0.03	+0.24 ±0.02	E2 +0.42 M1 -0.29	E2	6.5±0.2	7.5±0.3
96.0±0.5	7±2			6.5 ±2.0	E2 6.8 M1 2.1	1.5 ±0.5	E2 1.9 M1 0.5			E2	5.0±1	
511.2±0.5	105 ±15	.12 ±0.03	M1 .11 E2 .022	0.02 ±0.005	M1 .02 E2 .007			-0.20 ±0.03	M1 -0.28 E2 +0.40	M1	5.3±0.6	5.7±0.6
689.4±0.5	79 ±10	0.013 ±0.01	E1 .005 E2 .012 E3 .03							E1,E2	3.5±1	4.2±1
713.6±0.5	23 ±5	0.05 ±0.04	E3 .03 M1 .05 M2 .10							M1,E3	3.5±1	3.5±1.5
1536 ±1	97 ±10										1.2±0.2	1.60±0.15
203.7±0.5	40 ±4	0.9 ±0.3	M1 1.35 E3 .42	0.3 ±0.06	M1 .25 E3 3.2	0.06 ±0.02	M1 .06 E3 .95			M1	1.1±0.3	1.5±0.3
435.1±0.5	89 ±10	0.09 ±0.02	E3 .08 M1 .17	0.07 ±0.02	E3 .08 M1 .03	0.02 ±0.006	E3 .02 M1 .007	+0.3 ±0.1	E3 0.7 E2 0.4 M1-0.3	E3	1	1

a) Normalised to unity for 435 keV transition b) Normalised to total transition intensity of 100

c) Electron intensities have been normalised to yield the theoretical L conversion coefficient for the 253 keV transition

Figure Caption

Fig. 1. Experimental and calculated level schemes for ^{211}At. Only the lowest level of each spin ($I \geq 9/2$) is shown in the calculated scheme; the solid lines are the 3-proton states, and the dashed lines are 4p-1h states. The dominant configuration of each state is indicated.

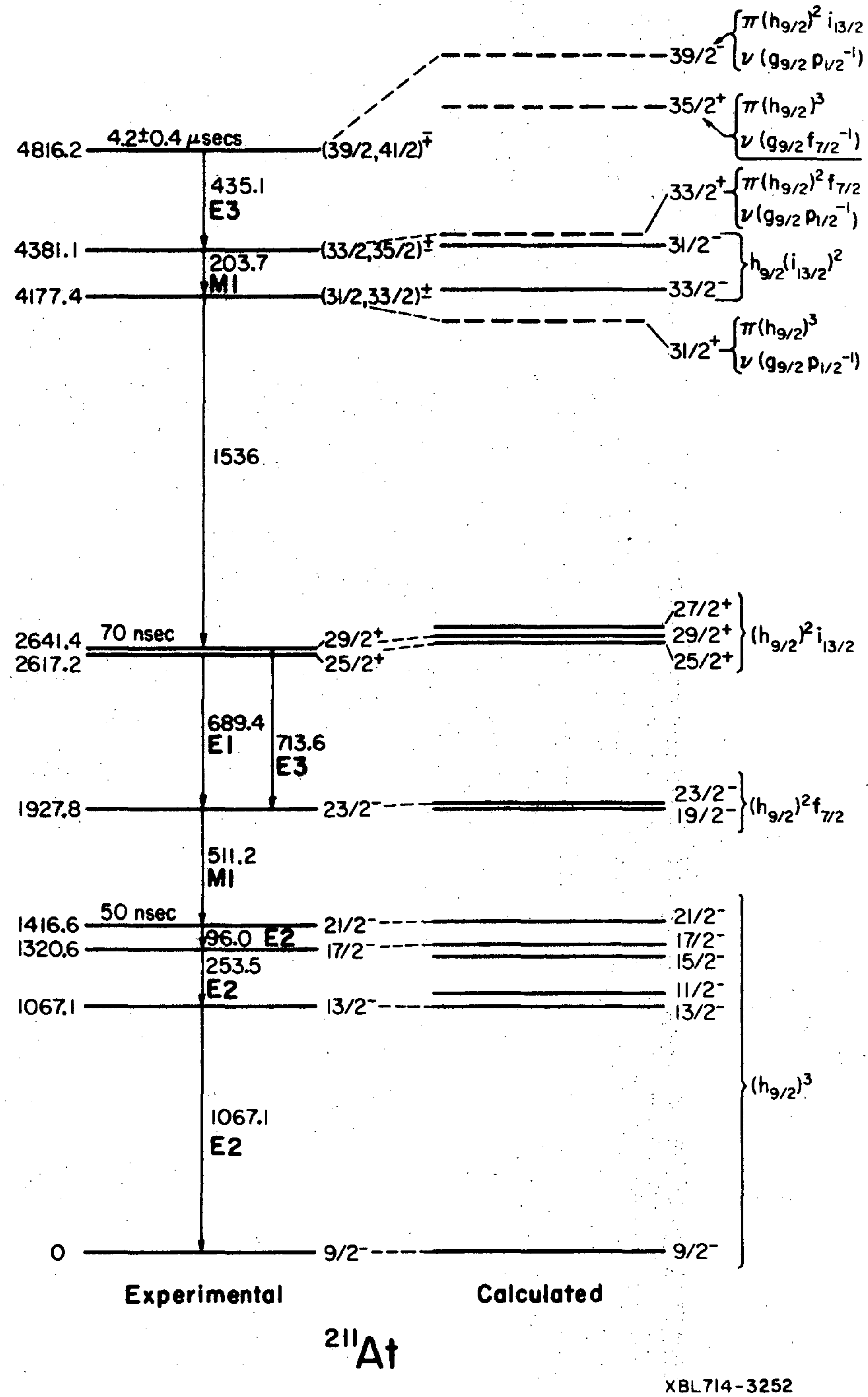
4816.2
4.2±0.4 μsecs
(39/2,41/2)∓
435.1
E3
4381.1
203.7
M1
(33/2,35/2)±
4177.4
(31/2,33/2)±
1536
2641.4
70 nsec
2617.2
29/2+
25/2+
689.4
E1
713.6
E3
1927.8
23/2−
511.2
M1
1416.6
50 nsec
21/2−
96.0 E2
1320.6
17/2−
253.5
E2
1067.1
13/2−
1067.1
E2
0
9/2−
39/2−
π(h9/2)2 i13/2
ν(g9/2 p1/2−1)
35/2+
π(h9/2)3
ν(g9/2 f7/2−1)
33/2+
π(h9/2)2 f7/2
ν(g9/2 p1/2−1)
31/2−
33/2−
h9/2(i13/2)2
31/2+
π(h9/2)3
ν(g9/2 p1/2−1)
27/2+
29/2+
25/2+
(h9/2)2 i13/2
23/2−
19/2−
(h9/2)2 f7/2
21/2−
17/2−
15/2−
11/2−
13/2−
(h9/2)3
9/2−
Experimental
Calculated
211At
XBL714-3252

Fig. 1

TECHNICAL INFORMATION DIVISION
LAWRENCE RADIATION LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720