Title
LEVEL INVERSION IN THE HYPERFINE STRUCTURE OF BROMINE-76. NUCLEAR MOMENTS OF BROMINE-76

Authors
Garvin, Hugh L.
Green, Thomas M.
Lipworth, Edgar.

Publication Date
1958-09-10

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

BERKELEY, CALIFORNIA

UCRL-8445

UNIVERSITY OF CALIFORNIA

Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

LEVEL INVERSION IN THE HYPERFINE STRUCTURE OF BROMINE-76. NUCLEAR MOMENTS OF BROMINE-76.

H. L. Garvin, T. M. Green, and E. Lipworth

September 10, 1958

Printed for the U. S. Atomic Energy Commission

LEVEL INVERSION IN THE HYPERFINE STRUCTURE OF BROMINE-76 NUCLEAR MOMENTS OF BROMINE-76*

H. L. Garvin, T. M. Green, and E. Lipworth

Radiation Laboratory
University of California
Berkeley, California

September 10, 1958

In the course of an investigation of 17-hr Br^{76} by the method of atomic beams it has been established that the ratio of the nuclear electric quadrupole and magnetic dipole interaction constants is such that the zero-field hyperfine levels do not occur in normal order.

The nuclear spin of Br^{76} is 1.[1] The electronic ground state is $^2P_{3/2}$; thus the permitted total angular momenta F (in units of $\hbar$) are 5/2, 3/2, and 1/2, and the hyperfine levels normally would be expected to possess this ordering; it is in fact found for Br^{76} that the F = 3/2 and F = 1/2 levels are inverted. This inversion has an interesting consequence which will be discussed below.

Br^{76} is produced by an (α, 3n) reaction on arsenic powder in the Berkeley 60-inch cyclotron. The radioactive bromine is extracted chemically and mixed with natural bromine carrier, and an atomic beam is produced by means of a discharge tube. The beam is collected upon silver-coated buttons which are counted in continuous-flow beta counters. Identification of the isotope is made by its method of production and decay half-life. The atomic-beams apparatus used for this experiment is arranged in the manner suggested by Zacharias to observe "flop in" type transitions.[2] The apparatus has been described elsewhere.[3]

In order to examine the dependence of the zero-field hyperfine-level separations on the nuclear magnetic-dipole and electric-quadrupole interaction constants "a" and "b," it is necessary to solve the zero-field Hamiltonian,

$$\frac{H}{a} = \vec{I} \cdot \vec{J} + b/a\, Qop. \qquad (1)$$

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

Here H is in frequency units; I and J are the nuclear and electronic angular momenta, respectively; and Qop is the quadrupole interaction operator.[4]

The solution results in the plot of Fig. 1. For $b = 0$ the levels are, of course, in normal order and their separations satisfy the Landé interval rule, but for values of $b/a > 2/3$ the $F = 1/2$ and $F = 3/2$ levels are inverted. With normal level ordering there are two and only two observable flop-in transitions[3] in an isotope with a $^2P_{3/2}$ electronic ground state and $I \geq 1$. For $I = 1$ these transitions are, in (F, m) notation,

$$\begin{aligned} &(5/2,\ -1/2) \leftrightarrow (5/2,\ -3/2), \\ &(3/2,\ 1/2) \leftrightarrow (3/2,\ -1/2). \end{aligned} \tag{2}$$

At the start of this investigation two flop-in transitions were observed in the linear Zeeman region with g_F values equal to those expected for transitions (2) above. The transitions were followed out to higher and higher values of magnetic field in order to determine the constants "a" and "b." It soon became apparent that the observed transition frequencies at different magnetic fields led to inconsistent values of a and b, and an inversion of the $F = 3/2$ and $F = 1/2$ levels was suspected. This inversion forces a rearrangement of the m values of the second of the above transitions, and has also the interesting consequence that a third additional flop-in transition, in the level $F = 1/2$, is permitted. The three observable flop-in transitions are now

$$\begin{aligned} &(5/2,\ -1/2) \leftrightarrow (5/2,\ -3/2), \\ &(3/2,\ 3/2) \leftrightarrow (3/2,\ 1/2), \\ &(1/2,\ 1/2) \leftrightarrow (1/2,\ -1/2). \end{aligned} \tag{3}$$

The g_F value for the new transition is unusually large; it is 2.22.

Figure 2 shows the energy levels of Br^{76} as a function of magnetic field. This diagram was calculated with the aid of an IBM 650 computer using the value of b/a given below. The three observable flop-in transitions are labeled α, β, and γ.

The resonances α and β have been observed to date at many different fields up to a maximum of 372 gauss. The resonance γ has been observed at four different fields of 1.99, 9.68, 18.79, and 39.7 gauss. The γ-resonance line widths are considerably greater than those of the α and β resonances, owing to the large g_F associated with the γ transition.

Currently the best fit to the data is obtained with b/a = 0.908. The values of the interaction constants are

$$a = 346 \pm 15 \text{ Mc},$$

$$b = 314 \pm 10 \text{ Mc}.$$

The uncertainties quoted are five times the experimental values of the error.

The hyperfine separations calculated from Eq. (1) are

$$\Delta\nu\ (5/2,\ 1/2) \approx 1069 \text{ Mc},$$

$$\Delta\nu\ (1/2,\ 3/2) \approx 188 \text{ Mc}.$$

Approximate values of the nuclear electric quadrupole moment and magnetic dipole moment can be obtained simply from b and a by a method due originally to Casimir.[5,6] The results, which are uncorrected for any relativistic, electronic core perturbation, or configuration interaction effects, are

$$|\mu| = 0.55 \pm .02 \text{ nuclear magneton}$$

$$|Q| = 0.27 \pm .01 \text{ barn}.$$

The sign of μ is not known, but μ and Q have opposite signs.

Work on Br^{76} is being continued in order to improve these results. A full account will be published later.

The authors wish to acknowledge the whole-hearted cooperation of the Radiation Laboratory Chemistry Department and Health Chemistry Division during the course of this work.

References

1. Green, Garvin, and Lipworth, Bull. Am. Phys. Soc. Ser. II, 3, 318 (1958).

2. J. R. Zacharias, Phys. Rev. 61, 270 (1942).

3. Garvin, Green, and Lipworth, Phys. Rev. III, 534 (1958).

4. For a definition of the quadrupole operator Qop see N. F. Ramsey, Molecular Beams (Oxford, 1950), Chap. III, p. 66 and Chap. IX, p. 272.

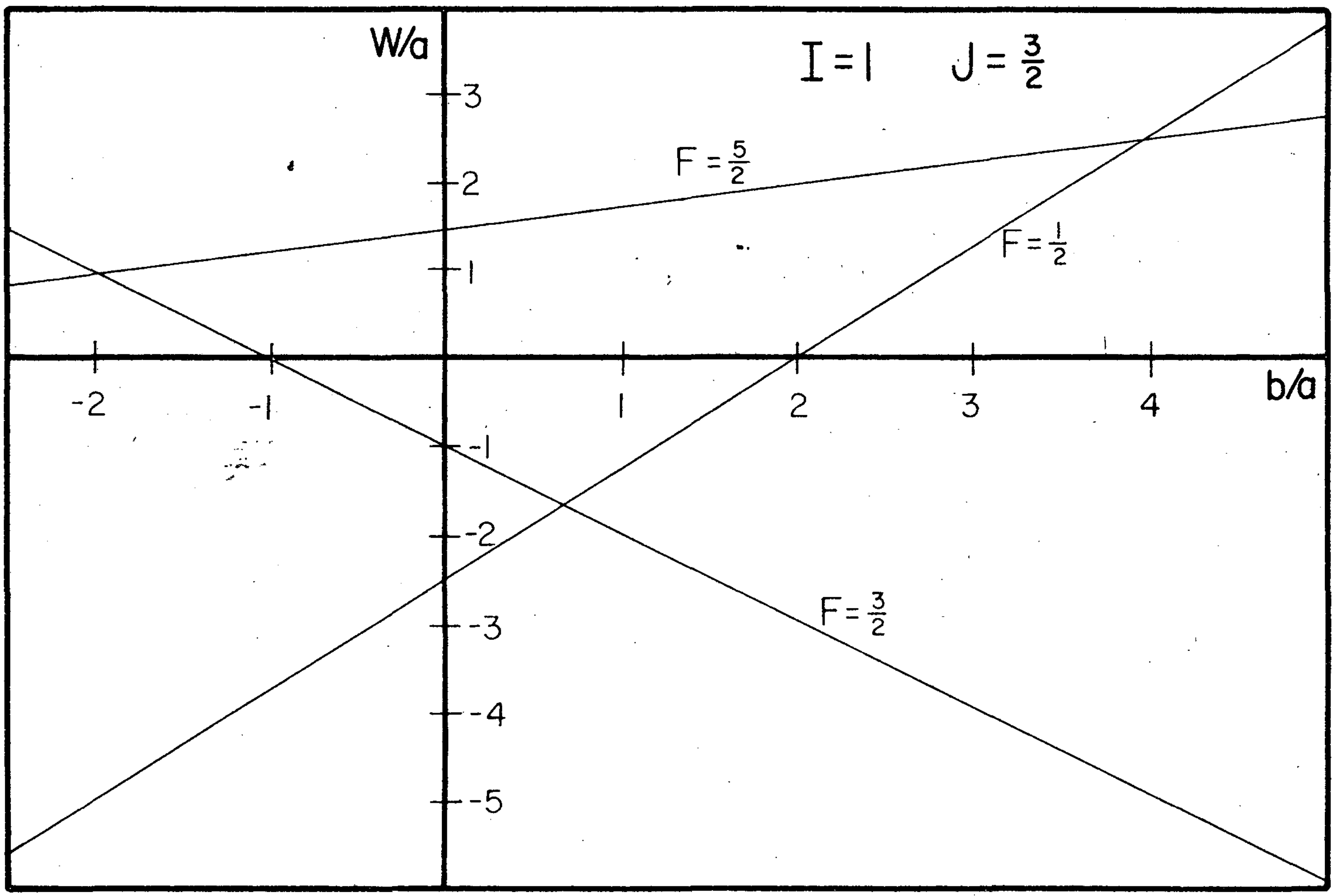
5. H. B. G. Casimir, On the Interaction Between Atomic Nuclei and Electrons (Teylers Tweede Genootschap, Haarlem, 1936) pp. 57, 58.

6. Davis, Feld, Zabel, and Zacharias, Phys. Rev. 76, 1076 (1949).

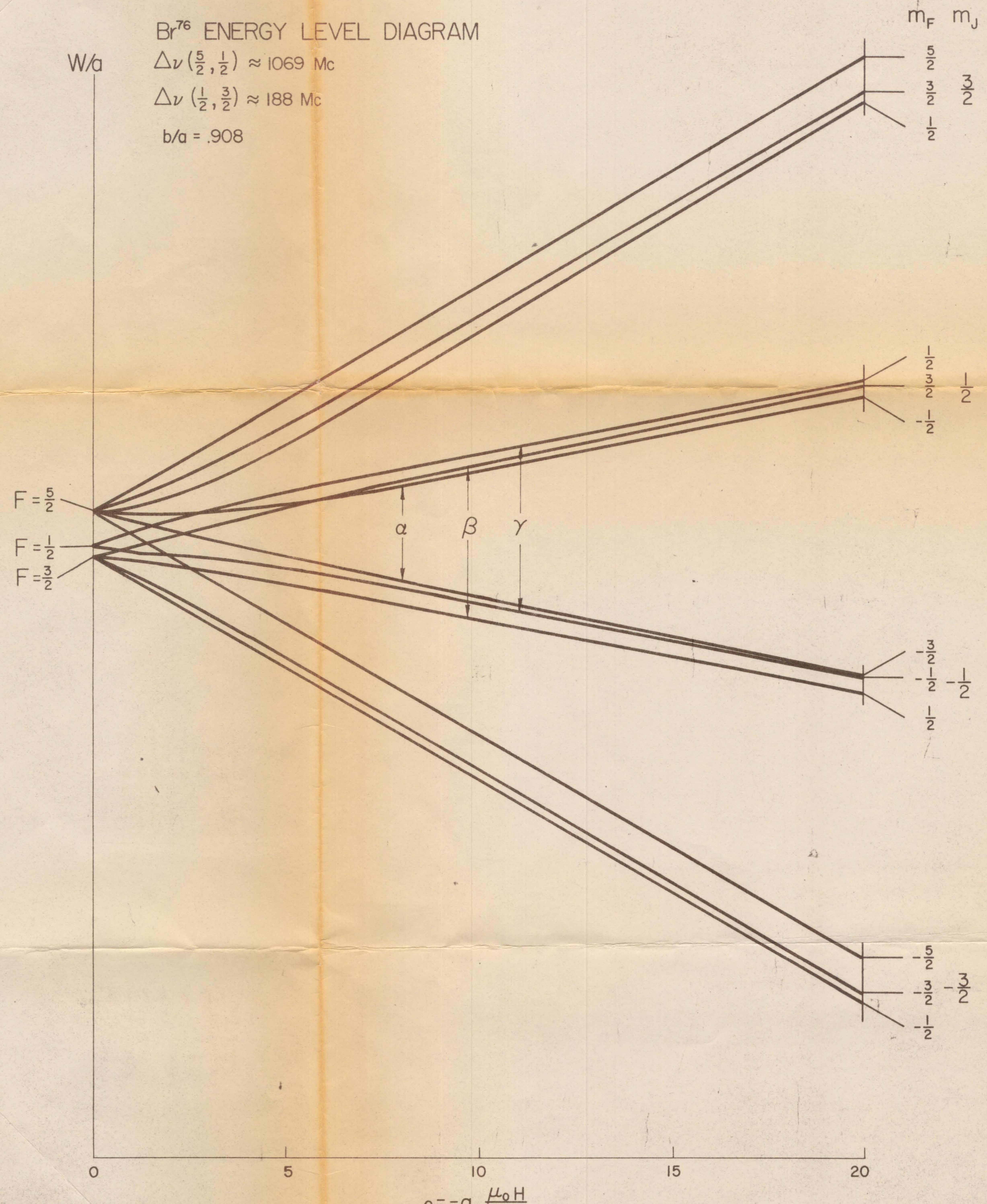
Figure Captions

Fig. 1. Energy levels of I = 1, J = 3/2 system at zero magnetic field as a function of b/a.

Fig. 2. Br^{76} energy-level diagram. This diagram was calculated with an IBM 650 computer, using a b/a value of 0.908. The hfs separations listed are approximate only.



F-1 52091-1



F-2

Fig 2

52092-3