platinum disk. The iodine was washed from the disk with sodium hydroxide solution containing sodium iodide carrier, and the mixture of radioactive and natural iodine was precipitated in acid solution by $NaNo_2$ oxidizing agent. After the iodine was extracted into carbon disulfide containing additional iodine carrier, the solution was evaporated to dryness under vacuum and introduced into the apparatus through a heated platinum tube to dissociate the I_2 molecules to iodine atoms. The beam was collected upon buttons previously sprayed with evaporated silver, and then counted in continuous-flow methane proportional counters.

The nuclear spin of the radioactive sample was measured by the method described in reference 1. For normal ordering of the hyperfine levels in atoms such as the halogens, with $^2P_{3/2}$ electronic ground state, two "flop-in" resonances are observable at each value of the magnetic field. For spin $I \geq 1$ these may be denoted as

$$\alpha: (F=I+3/2, M_F=-I+1/2) \rightarrow (F=I+3/2, M_F=-I-1/2),$$

and

$$\beta: (F=I+1/2, M_F=-I+3/2) \rightarrow (F=I+1/2, M_F=-I+1/2).$$

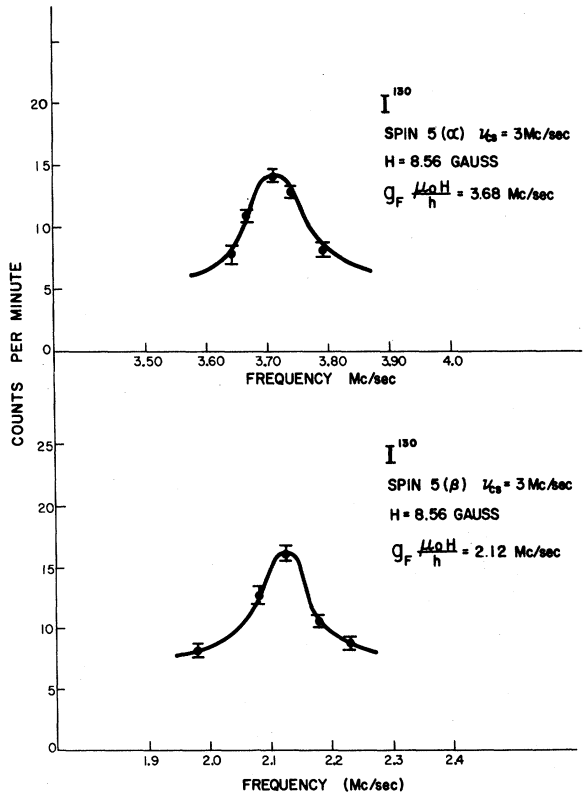

FIG. 1. Spin 5(α) and 5(β) resonances in I^{130}.

Both resonances have been observed in I^{130} at three different magnetic fields of 2.86, 8.56, and 14.24 gauss. Figure 1 exhibits two typical resonances obtained at a field of 8.56 gauss. Positive identification of the isotope was made by means of its decay half-life, and by analysis of its gamma-ray spectrum using a 100-channel pulse-height analyzer.

The value of 5 for the nuclear spin of I^{130} is consistent with the single-particle shell model of the nucleus.[2] The spins of I^{129} and I^{131}, both with an even number of neutrons, are known to be 7/2. If in I^{130} the odd proton is assigned to the $1g_{7/2}$ level and the odd neutron to the $2d_{3/2}$ level, Nordheim's weak rule applies, and the observed spin results from a coupling of j_n and j_p to the maximum permissible value. If on the other hand the odd neutron is assigned to the neighboring $1h_{11/2}$ level, Nordheim's strong rule applies and a spin of 2 can be expected.[3] It is thus likely that the odd neutron in I^{130}, as in $_{54}Xe_{77}^{131}$, occupies the $2d_{3/2}$ level.

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[1] Garvin, Green, and Lipworth, Phys. Rev. 111, 534 (1958).

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

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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 $(\alpha, 3n)$ 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,

$$H/a = \vec{I}\cdot\vec{J} + (b/a)Q_{op}. \qquad (1)$$

Here H is in frequency units; I and J are the nuclear and electronic angular momenta, respectively; and Q_{op} 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,

$$(5/2, -1/2) \leftrightarrow (5/2, -3/2),$$
$$(3/2, 1/2) \leftrightarrow (3/2, -1/2). \qquad (2)$$

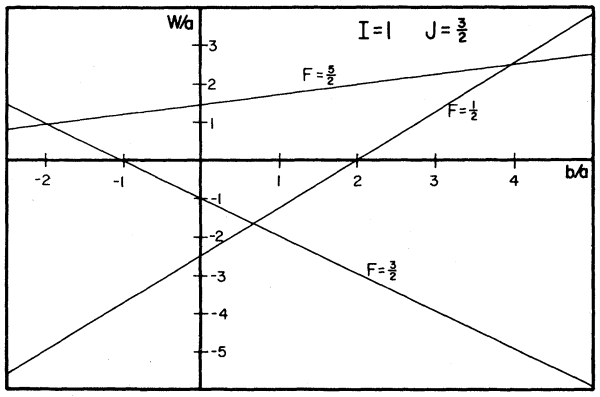

FIG. 1. Energy levels of $I=1$, $J=3/2$ system at zero magnetic field as a function of b/a.

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

$$(5/2, -1/2) \leftrightarrow (5/2, -3/2),$$
$$(3/2, 3/2) \leftrightarrow (3/2, 1/2), \qquad (3)$$
$$(1/2, 1/2) \leftrightarrow (1/2, -1/2).$$

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

$$a = 346 \pm 15 \text{ Mc/sec},$$
$$b = 314 \pm 10 \text{ Mc/sec}.$$

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

The hyperfine separations calculated from Eq. (1) are

$$\Delta\nu(5/2, 1/2) \approx 1069 \text{ Mc/sec},$$
$$\Delta\nu(1/2, 3/2) \approx 188 \text{ Mc/sec}.$$

Approximate values of the nuclear electric

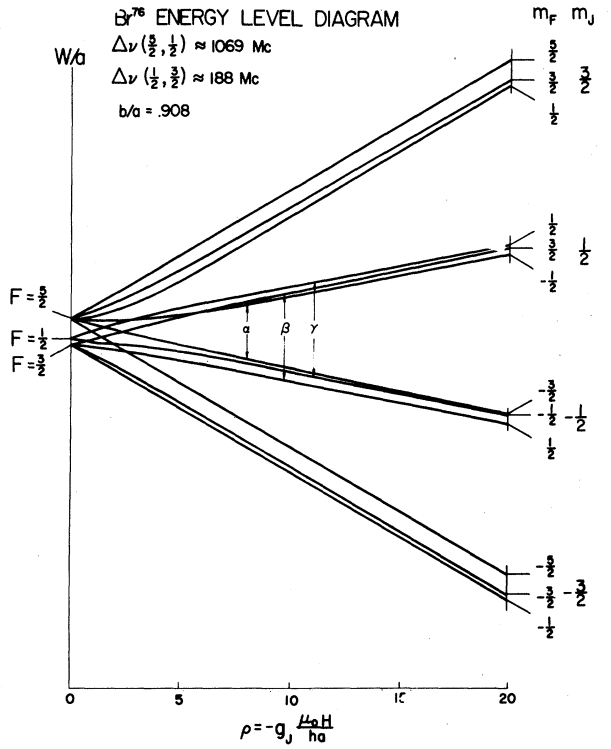

FIG. 2. Br^{76} energy-level diagram. This diagram was calculated with an IBM-650 computer, using a b/a value of 0.908. The hfs separations listed are approximate only.

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

$$|\mu| = 0.55 \pm 0.02 \text{ nuclear magneton},$$
$$|Q| = 0.27 \pm 0.01 \text{ barn}.$$

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 wholehearted cooperation of the Radiation Laboratory Chemistry Department and Health Chemistry Division during the course of this work.

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

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SPIN OF Fe^{57}

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The spin of the stable isotope Fe^{57} has been directly observed to be $\frac{1}{2}$ from the electron spin resonance spectrum of iron-doped silicon. Samples were prepared by alloying several milligrams of iron[1] enriched to contain 84.1% Fe^{57} onto silicon crystals 3 mm × 3 mm × 10 mm. The iron was diffused into the silicon bars by placing them in evacuated quartz tubes held at 1200°C for 24 hours. The samples were quenched by dropping the quartz tubes into water, were chemically etched, and were placed in the reflection cavity of a spectrometer operating at about 14 kMc/sec.

Figure 1 shows the dispersion derivative at approximately 10°K as displayed on the recorder of the spectrometer for the magnetic field in a (111) crystal direction. The central pattern (centered about $g = 2.0699$) is due to the 16% abun-

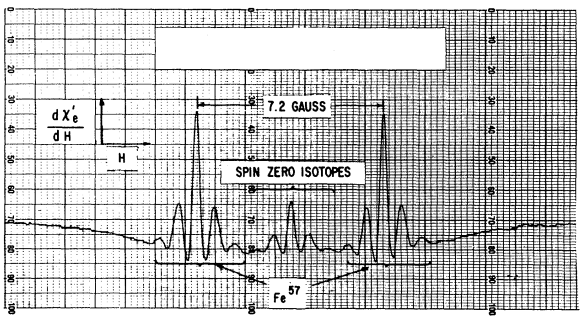

FIG. 1. The derivative of the dispersion at approximately 10°K in a silicon crystal doped with iron enriched to contain 84.1% Fe^{57}. The central pattern is due to the 16% abundant Fe isotopes of spin zero. The two outer patterns represent hyperfine interaction with Fe^{57}.