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Publication Date
1961-06-19

UCRL-9757

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Berkeley, California

Contract No. W-7405-eng-48

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ABSTRACT

The hyperfine structure of ${}_{95}\mathrm{Am}^{242}$($T_{1/2}$= 16 hr) in the $J = 7/2$ electronic ground state has been studied by the atomic-beam technique using radioactive detection. The nuclear spin is found to be $I = 1$. The measured values of the magnetic-dipole interaction constant A and the electric-quadrupole interaction constant B are $A = \pm 10.124(10)$ Mc and $B = \pm 69.639(40)$ Mc, respectively. Combining these measurements with optical spectroscopic and atomic-beam data for Am^{241}, we infer the nuclear magnetic-dipole moment to be $\mu_I = \pm 0.33$ nm and the nuclear quadrupole moment $Q = \mp 2.76$ barns. These results are discussed in terms of the Bohr-Mottelson nuclear model.

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INTRODUCTION

The 16-hr state of Am^{242} has recently been shown to be the ground state of an isomeric pair, the excited member having a half-life of 152 years.[1] Since this isotope is in the region where nuclei are known to exhibit relatively large deformations, the properties of the ground state ought to serve as a test for the Bohr-Mottelson-Nilsson model of the nucleus.[2,3] This model makes definite predictions for the spins and moments of the ground state, and these measurements are concerned with establishing the validity of these predictions.

The properties of an odd-odd nucleus are determined by the states of the last odd nucleons and the coupling between them. Information concerning the probable state assignment of the odd proton in the nuclear ground state can be inferred from the spin of 5/2 measured for Am^{241} and Am^{243}.[4] These are consistent with the assignment of 5/2-[5 2 3]. The odd-neutron orbital is 5/2+[6 2 2] according to the assignment of Mottelson and Nilsson[5] on the basis of the observed alpha decay of Am^{243} to the ground state of Pu^{239}. Finally, relative transition probabilities of Am^{242} decay to the 0^+ and 2^+ states of Pu^{242} clearly indicate that the ground state of Am^{242} is the lowest level of a $K = 0$ rotational band. The consistency of these assignments with our measurements is discussed in the conclusions.

In order to determine the nuclear properties from hyperfine structure constants, the quantities characterizing the electronic state under observation must be known. These can be deduced from extensive measurements on the electronic ground state of americium-241 made by optical spectroscopy[4] and atomic beams.[6] The experimentally determined quantities that are pertinent to the measurements reported here are, for the electronic ground state:

electronic angular momentum $J = 7/2$

spectroscopic splitting factor $g_J = -1.9371(10)$

magnetic field at the nucleus $\langle H_z \rangle_{J, m_J = J} = 2.3 \times 10^6$ gauss

quadrupole field at the nucleus $\langle q_J \rangle_{J, m_J = J} = 7.3 \times 10^{23}$ cm^{-3}.

BEAM PRODUCTION AND DETECTION

Americium-242 is produced by neutron irradiation of Am^{241}. Approximately 5 mg of americium oxide powder was poured into an aluminum capsule with a screw-on cap. The capsule was sealed in a quartz tube, which was placed in a larger aluminum capsule. The package was bombarded for 16 hr at a flux of 9.5×10^{13} neutrons/sec-cm^2 in the core position of the General Electric nuclear reactor at Vallecitos, California. A stable beam of americium atoms was produced from the americium oxide by the same lanthanum reduction technique that was used successfully with Am^{241}.[6]

The americium beam was detected by means of its radioactivity. Freshly-flamed platinum discs placed at the detector position collected the impinging americium. After exposure, the platinum disc was removed from the apparatus and counted in flow proportional beta counters. The presence of Am^{241} decay does not significantly contaminate the sample. A typical neutron bombardment yields approximately 1000 times more Am^{242} activity than Am^{241} activity. The isotope is identified from its half-life and gamma-ray spectrum.

OBSERVATIONS AND DATA ANALYSIS

A spin search at a magnetic field of 0.7 gauss clearly indicates a nuclear spin I = 1. Resonances associated with transitions in the three states with total angular momentum F = 5/2, 7/2, and 9/2 were observed at several magnetic fields. The data are presented in Table I. From this data, the separations of the hyperfine levels can be predicted with sufficient accuracy to warrant a search for the direct transitions. The results of such a search at 0.7 gauss are shown in Fig. 1 and tabulated in Table I. There are 12 possible $|\Delta F| = 1$, $|\Delta m| = 1$ transitions between the levels F = 9/2 and F = 7/2. The transition $(9/2, -1/2 \longleftrightarrow 7/2, 1/2)$ was identified from its field dependence by observing it again at 1.4 gauss. The transition $(5/2, 1/2 \longleftrightarrow 7/2, 1/2)$, is the only $|\Delta F| = 1$, $|\Delta m| = 0$ transition between the levels F = 5/2, F = 7/2.

The data taken can be analyzed by means of the Hamiltonian

$$\mathcal{H} = A\vec{I}\cdot\vec{J} + \frac{B[3(\vec{I}\cdot\vec{J})^2 + 3/2\,(\vec{I}\cdot\vec{J}) - I(I+1)J(J+1)]}{2IJ(2I-1)(2J-1)} - g_J\mu_0 H,$$

where the first term arises from nuclear moment interaction with the electronic magnetic field, the second term is the quadrupole interaction, and the third term is the interaction of the electronic moment with the external field (H). By means of an IBM 704 program described elsewhere,[6] the values of the hyperfine-structure constants A and B that give the best fit to our data were determined. The results are

$A = \pm\ 10.124(10)$ Mc

$B = \pm\ 69.636(40)$ Mc.

In this analysis, we have taken $g_J = -1.9371(10)$ and $J = 7/2$. When the data is analyzed for an optimum value of g_J as well as A and B, no significant change occurs in the results. From Fig. 2 we see that the ratio

B/A = + 6.88 indicates that the levels $F = 5/2$ and $F = 7/2$ are inverted, so that the energy level scheme is as shown in Fig. 3.

NUCLEAR MOMENTS

The hfs constants of two isotopes of the same element are related by $AI/\mu_I = A' I'/\mu_{I'}$, and $B/Q = B'/Q'$. Manning, Fred, and Tomkins determined the nuclear moments of Am^{241} from optical spectroscopic data to be $\mu_I = 1.4$ nm and $Q = 4.9$ barns.[4] The hfs constants of Am^{241} as measured by the method of atomic beams are $A = \pm 17.144(8)$ Mc and $B = \mp 123.82(10)$ Mc.[6] The nuclear spin of Am^{241} is $I = 5/2$. Therefore we have

$$\mu_I(Am^{242}) = \pm 0.33 \text{ nm}$$

and

$$Q(Am^{242}) = \mp 2.76 \text{ barns.}$$

These values can be best interpreted in terms of the state assignments for the last odd proton and neutron quoted in the introduction. If these assignments are correct, then the odd-odd coupling rules of Gallagher and Moszkowski[7] predict that $K = |\Omega_p - \Omega_n| = 0$ in the nuclear ground state. The spin-1 result indicates that the $I = 1$ level of the $K = 0$ rotational band is displaced below the $I = 0$ level. This situation is analogous to the one in Pa^{233}, where we have $K = 1/2$ but $I = 3/2$.[8] For a $K = 0$ rotational band, the nuclear angular momentum, I, must be perpendicular to the symmetry axis; hence there can be no contribution to the nuclear dipole moment from the odd nucleons. The nuclear core has a magnetic moment $\mu_I = g_R I$, where g_R is the g factor of the collective motion of the core. For a uniformly charged nucleus, g_R is equal to Z/A and therefore $\mu_I(\text{theor.}) = + 0.39$ nm. According to the collective model of the nucleus, the nuclear quadrupole moment Q, is given in terms of the intrinsic quadrupole moment Q_0 by

$$Q = \frac{3K^2 - I(I+1)}{(I+1)(2I+3)} Q_0 = -Q_0/5. \tag{1}$$

If we assume that the intrinsic Q_0 of Am^{242} is the same as that of Am^{241}, then the predicted Q of Am^{242} is Q(theor.) = - 2.74 barns. The agreement between the theoretical and experimental values of the nuclear moments is excellent, if the positive sign for A and B is assumed. This choice of sign supports a previous calculation which indicates that the discrepancy in the sign of one of the hfs constants of Am^{241} with that predicted from a theory based on the breakdown of L-S coupling is due to effects which change the sign of A, but not of B.[6]

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*This work was done under the auspices of the U. S. Atomic Energy Commission.

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Table I. Observed resonances in Am^{242}.

Data No.	H (gauss)	$\nu_{obs.}$ (Mc)	$\nu_{obs.} - \nu_{calc.}$ (Mc)	Transition
1	2.818(27)	5.95(15)	-0.018	a
2	2.818(27)	7.35(15)	0.051	b
3	2.818(27)	9.73(15)	-0.064	c
4	5.566(27)	11.95(10)	0.105	a
5	5.566(27)	14.70(10)	-0.003	b
6	5.566(27)	19.25(8)	0.060	c
7	9.564(26)	20.60(12)	0.067	a
8	9.564(26)	25.90(10)	0.023	b
9	9.564(26)	32.60(12)	0.143	c
10	14.678(31)	31.96(12)	-0.028	a
11	14.678(31)	40.55(10)	0.024	b
12	14.678(31)	48.91(12)	0.191	c
13	21.931(35)	49.20(20)	0.109	a
14	21.931(35)	61.50(20)	0.065	b
15	21.931(35)	70.35(20)	0.069	c
16	46.077(47)	112.20(30)	0.346	a
17	46.077(47)	130.00(40)	0.113	b
18	46.077(47)	133.95(30)	0.147	c
19	540.903(220)	1467.80(80)	0.471	c
20	0.711(028)	52.04(10)	-0.004	d
21	0.711(28)	111.125(75)	0.001	e
22	1.418(28)	109.680(75)	0.000	e

[a] (9/2, - 1/2 ↔ 9/2, - 3/2).

[b] (7/2, 3/2 ↔ 7/2, 1/2).

[c] (5/2, 1/2 ↔ 5/2, - 1/2).

[d] (5/2, 1/2 ↔ 7/2, 1/2).

[e] (9/2, - 1/2 ↔ 7/2, 1/2).

FIGURE CAPTIONS

Fig. 1. Results of a search at 0.7 gauss.

Fig. 2. Energy level ordering vs. B/A for Am^{242}.

Fig. 3. Energy levels of Am^{242}.

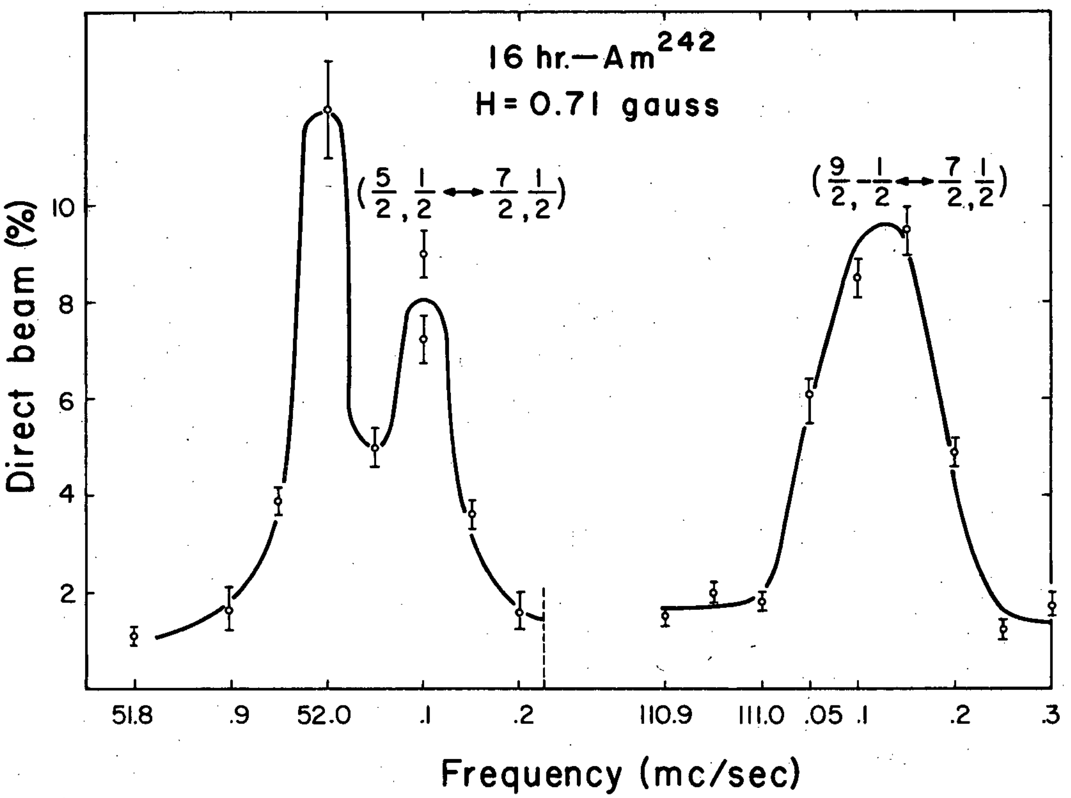

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Fig. 1.

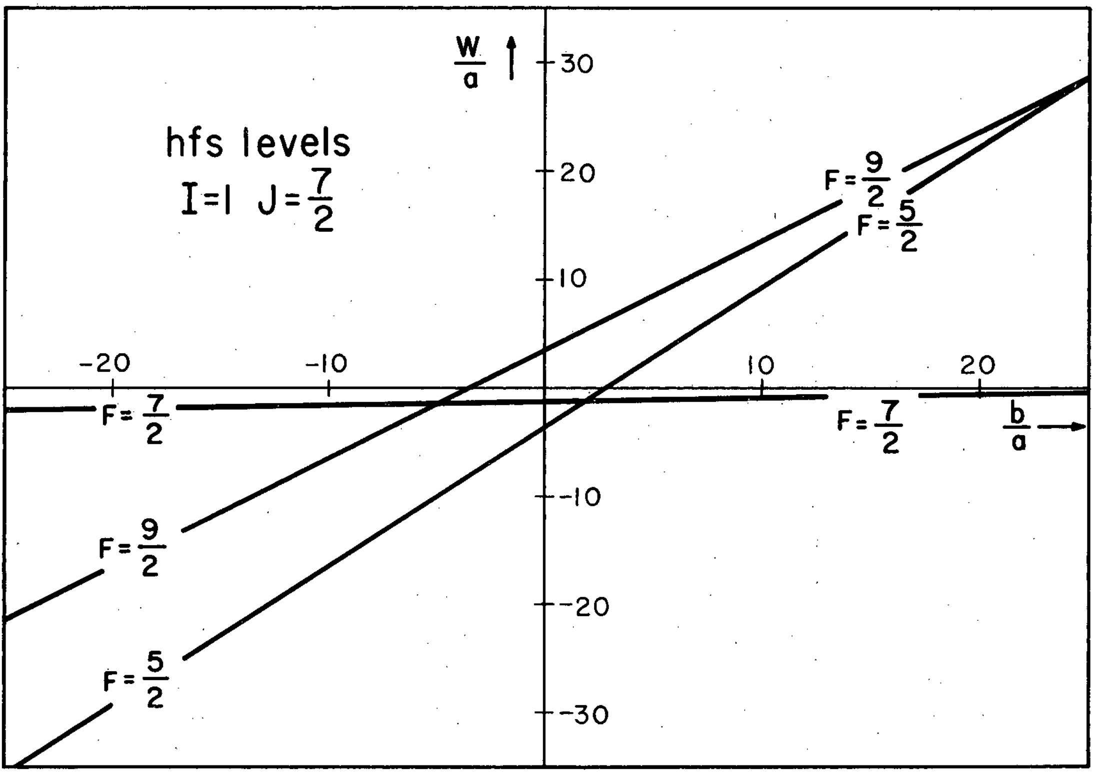

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Fig. 2

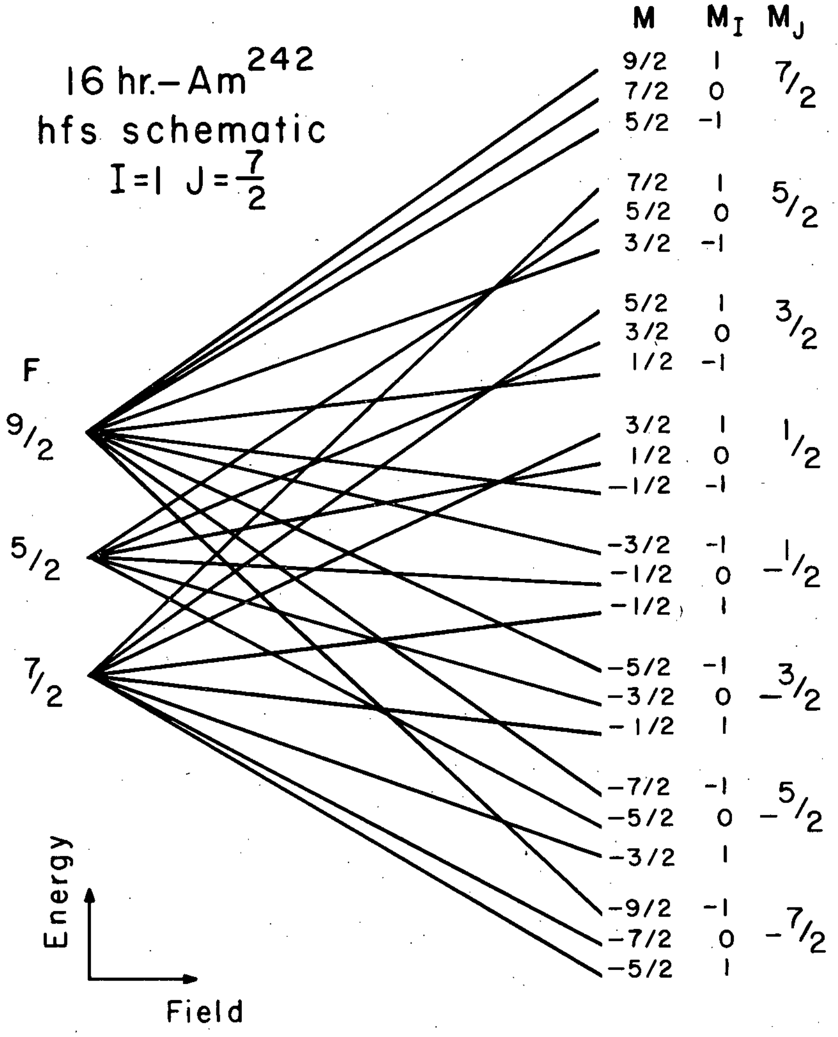

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Fig. 3