This is approximately one and one-half percent of the second-order correction[3] and of the opposite sign, thus decreasing the moment.

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** National Research Council Postdoctoral Fellow.
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[2] Private communication from Professor Feynman.
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Hyperfine Structure of $4\,^3P-4\,^3D$ of the Spectrum of Al II

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WHEN the separations of a term multiplet in an atomic spectrum are so small that they are comparable with or smaller than the hyperfine splittings which are caused by the interaction between nuclear spin and outer electrons, the hyperfine structure exhibits an anomalous feature,[1] which has not yet been fully accounted for. In order to clarify this problem, study of the hyperfine structure of the group of lines of Al II ($4\,^3P-4\,^3D$) at λλ6243, 6231 and 6226 has been undertaken. The structure of these lines was studied previously by Paschen,[1] but his resolving power does not seem to be sufficient for our purpose.

The spectrum was excited in a water-cooled aluminum hollow cathode discharge tube filled with neon of a few mm Hg pressure. The hyperfine structure was examined by the use of a glass Lummer plate (thickness=4.7 mm), a quartz Lummer plate (thickness=4.4 mm) and a Fabry-Pérot etalon. The result of the measurements is given in the upper part of Fig. 1. The main components of λλ6243 and 6231 were so strong and broad (this is shown in Fig. 1 by shaded lines) that their positions relative to the other weaker components were less definite than the mutual distances of the weaker components.

The hyperfine splittings of the final levels, $4\,^3P_{2,1,0}$ are known by the work of Heyden and Ritschl;[2] they obey the usual rule on hyperfine structure. In order to explain the structure of the above-mentioned lines theoretically, we need only consider the structure of $4\,^3D$ and the transition probability from each level of $4\,^3D$ to that of $4\,^3P$. The total Hamiltonian is given by

$$H=H_0(j)+A(\mathbf{I}+\mathbf{s}),$$

where $\mathbf{I}$ and $\mathbf{s}$ are the spin of the nucleus and the 3*s*-electron respectively, and A is their coupling constant. Taking into account both the multiplet and the hyperfine splitting simultaneously from the outset of the calculation of the energy levels of $4\,^3D$, secular equations were set up for each value of F, the hyperfine structure quantum number, in the scheme in which $\mathbf{J}^2$ is diagonal. These secular equations involve three parameters, A, $\alpha=H_0(^3D_3)-H_0(^3D_1)$ and $\beta=H_0(^3D_2)-H_0(^3D_1)$. α and β are differences of the diagonal elements of H_0 and represent the magnitudes of the triplet separations of $4\,^3D$. Assuming that $A=0.172$ cm^{-1},[2] the secular equations were solved numerically for various values of α and β, and at the same time the intensities of all hyperfine components were calculated.[3] The best fit for α and β was found to be -0.70 cm^{-1} and -0.31 cm^{-1}, respectively. The calculated separations of the hyperfine levels of $4\,^3D$ are given in Table I, and the hyperfine structure of the three lines obtained by this numerical calculation is given in the lower part of Fig. 1. Agreement between observation and theory is satisfactory within the limit of our resolving power.

TABLE I. Hyperfine separations of the terms $4\,^3D_{3,2,1}$.

	$^3D_1$	$^3D_2$	$^3D_3$
$F(11/2)$			0.208
$F(9/2)$		0.187	0.135
$F(7/2)$	−0.100	0.017	0.083
$F(5/2)$	−0.061	0.008	0.052
$F(3/2)$		0.004	0.029
$F(1/2)$			

$F(7/2)(^3D_1)-F(9/2)(^3D_2)=-0.210$ cm^{-1}
$F(1/2)(^3D_2)-F(11/2)(^3D_3)=-0.080$ cm^{-1}

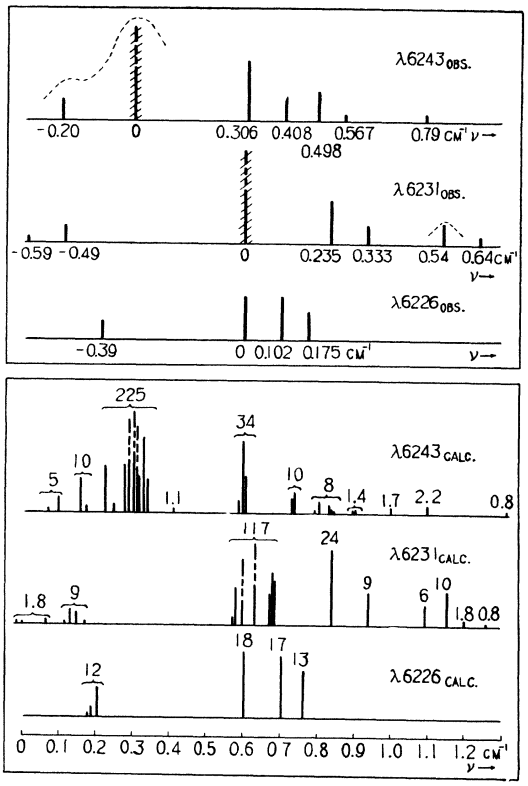

FIG. 1. Hyperfine structure of λλ6243($4\,^3P_2-4\,^3D$), 6231 ($4\,^3P_1-4\,^3D$), and 6226 ($4\,^3P_0-4\,^3D$) of Al II.

The values of α and β thus found are indeed of the same order of magnitude as the hyperfine structure constants, A, and the group of lines of Al II $4\,^3P-4\,^3D$ has proved to be a typical example in which the ordinary multiplet character is strongly perturbed by the hyperfine splittings, resulting in an unusual structure.

In conclusion the author wishes to express his sincere gratitude to Professor Murakawa for his cordial and continued guidance in this work.

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Nuclear Spin and Magnetic Moment of Cs^{135} and Cs^{137} *

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AN atomic beam magnetic resonance apparatus with a mass spectrometric detector was used by Luther Davis, Jr., to measure the nuclear spin and magnetic moment of Cs 137.[1] This letter reports similar measurements made on a second aliquot of

TABLE I. $F=4$, $(-4=m_F\leftrightarrow m_F=-3)$. Resonances in Cs 133 and Cs 137.

Observed frequency megacycles·sec.$^{-1}$ $f133$	$f137$	Computed h.f.s. $\Delta\nu$ (137) (μ_I positive) megacycles·sec.$^{-1}$
45.092 ±0.020	44.934 ±0.020	10197.0 ±250
49.338 ±0.010	49.162 ±0.015	10110.0 ±130
80.289 ±0.013	79.842 ±0.026	10129.5 ±80
360.56 ±0.04	352.30 ±0.04	10123.3 ±12

Weighted average 10,125 ±9 megacycles·sec.$^{-1}$
$\mu_I=2.833\pm0.01$ nuclear magnetons

TABLE II. $F=4$, $(-4=m_F\leftrightarrow m_F=-3)$. Resonances in Cs 133 and Cs 135.

Observed frequency $f133$	$f135$	Computed h.f.s. $\Delta\nu$ (135) μ_I positive	μ_I negative
45.092 ±0.020	44.996 ±0.020	9777.0 ±240	10800 ±240
49.338 ±0.010	49.235 ±0.010	9717.0 ±100	10600 ±100
80.289 ±0.013	79.998 ±0.026	9769.0 ±80	10290 ±80
360.56 ±0.040	355.55 ±0.040	9732.1 ±9	9824 ±9
408.36 ±0.040	402.19 ±0.040	9717.0 ±7	9795 ±7

Weighted average 9724.0 ±8 megacycles·sec.$^{-1}$
$\mu_I=2.721\pm0.01$ nuclear magnetons

the original sample of fission product cesium (supplied by the Isotopes Division of the AEC), but with the mass discrimination of the spectrometer improved to the point that resonance transitions could be observed for Cs 135 in the presence of the 133 carrier, as well as the 137 transitions.

The apparatus is arranged to detect those atoms in the beam which satisfy the conditions: (1) They belong to the alkali family, and have specified mass number. (2) They undergo a change in state in the transition field which corresponds to a change of ±1 in the quantum number m_j for strong magnetic fields. Condition 1 identifies the isotope unequivocally. Condition 2 coupled with the selection rule $\Delta m_F=\pm1$ identifies the observable low frequency line as belonging to the transition

$$F=I+\tfrac{1}{2},\quad [m_F=-(I+\tfrac{1}{2})\leftrightarrow-(I-\tfrac{1}{2})=m_F].$$

In weak magnetic field the frequency of the line is very nearly

$$1.400H/(I+\tfrac{1}{2})\text{ megacycles sec.}^{-1},$$

where H is the magnetic field in gauss and I the nuclear spin.[2,3]

Figure 1 exhibits the refocused beam intensity observed when the magnetic field is held constant and the oscillator frequency varied. With the mass spectrometer set in the 133 position the curve labeled 133 was obtained, and so forth. The background in the 133 position is principally due to fast 133 atoms in the penumbra of the beam. In the 137 position fast 137 atoms and residual ions in the spectrometer account for the background. In the 135 curve the fast 135 atoms and residual ions in the spectrometer account for part of the background, and the rest is due to 133 atoms incompletely discriminated against, as shown by the smaller maximum at the resonance frequency of the 133. The fact that all the peaks occur at nearly the same frequency shows that the spin of Cs 135, like that of 133 and 137, is 7/2.

The displacements of the 135 and 137 peaks from the 133 resonance frequency are due to differing values of the hyperfine structure separation, and permit calculation of the h.f.s. $\Delta\nu$ and the nuclear magnetic moment. The method is similar to that used by Zacharias.[4] It is assumed that μ_I is proportional to $\Delta\nu$; this might give rise to small errors in μ_I but to much smaller ones in $\Delta\nu$.[5] Using the values of Kusch, Millman, and Rabi,[6] namely,

$$\Delta\nu_{133}=9192.6\text{ megacycles}\cdot\text{sec.}^{-1},$$
$$\mu_{133}=2.572\text{ nuclear magnetons},$$

the values of $\Delta\nu_{135}$ and $\Delta\nu_{137}$ which best fit the Breit-Rabi formula[2] are computed from the observed resonance frequencies. This has been done for a number of values of magnetic field.

Table I presents the results for 137, which agree with the earlier ones.[1] Table II presents the results for 135, calculated alternatively for positive or negative μ_I. μ_I must be taken positive in order to obtain consistent values of $\Delta\nu$. The weighted average of the h.f.s. is computed to be 9724.0±8 megacycles·sec.$^{-1}$ and the nuclear magnetic moment 2.721 nuclear magnetons.

I wish to acknowledge the assistance of Hin Lew and the other members of the atomic beam laboratory.

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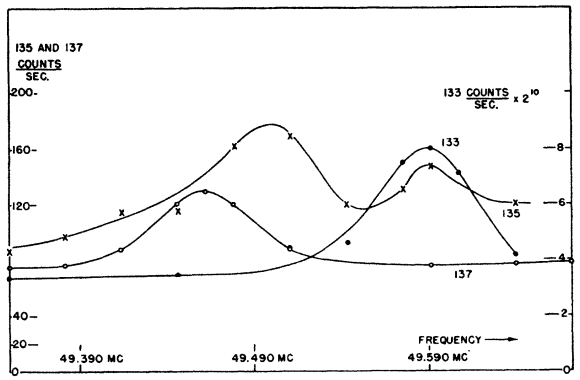

FIG. 1. Low frequency resonance transitions in Cs 133, 135, and 137.

The Energy Distribution of Fission Fragments from Pu^{239}

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THE energy distribution of fission fragments from Pu^{239} has been measured as a continuation of the work on U^{235} and U^{233}, reported previously.[1] The experimental arrangement was very similar to that previously described. The results, in particular the nature of the "gated" distributions, were similar to those in the other fissile materials. A comparison of these results with those of Deutsch and Ramsey[2] is shown in Table I, in which the fragment energies are uncorrected for source and collimator losses for proper comparison. The corrected values obtained in the present experiment are 94.6 and 65.2 Mev for the light and heavy frag-

TABLE I. Comparison of present experiment with Deutsch and Ramsey for fission in Pu^{239}.

	Present* experiment	Deutsch* and Ramsey
Most probable energy of light fragment (Mev)	93.3	93
Most probable energy of heavy fragment (Mev)	63.9	65
Ratio of most probable energies	1.47	1.43
Most probable mass ratio (from an equal ratio interval curve)	1.35	1.32
Width at half-maximum of high energy peak (Mev)	13.6	13
Width at half-maximum of low energy peak (Mev)	24	21
Ratio of minimum to high energy peak percent	23	11
Ratio of peak heights	1.47	1.48

* Values uncorrected for source and collimator losses.