and O_2, assuming the sum of the energy losses of the constituents equals that of the compound. Using this value for carbon one may then obtain chlorine from CCl_4. Calculating the L and M values for carbon and chlorine, it is then possible to calculate, using Eq. (1), the energy loss for the compounds. The calculated results are drawn as the smooth curves in Fig. 5.

5. From data taken with hydrogen for equal velocities, the energy loss of protons, deuterons, and tritons is the same within the experimental error.

The collaboration of my colleagues in the group, W. R. Arnold, G. A. Sawyer, and E. J. Stovall, Jr., is gratefully acknowledged. Further, it is a pleasure to record the guidance and support of J. L. Tuck.

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The Microwave Absorption Spectum of $(O^{16})_2$ and $O^{16}O^{17}$*

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The theory of the fine structure of O_2 is made somewhat more complete and fitted to the observed microwave spectrum. This gives $B_0=43\,102\pm5$ Mc/sec for $O^{16}O^{16}$. In addition there is evidence for the effect of higher order terms such as centrifugal distortion on the magnetic interaction constants. Magnetic hyperfine structure has been observed in the spectrum of $O^{16}O^{17}$. The spectrum agrees with that predicted on the basis of a perturbation Hamiltonian $b\mathbf{I}\cdot\mathbf{S}+cI_zS_z$, where $b=-102$ Mc/sec and $c=140$ Mc/sec. The value of 5/2 for the spin of O^{17} is confirmed.

INTRODUCTION

THE oxygen molecule is unusual in having a $^3\Sigma$ ground state; that is, it has an electron spin momentum of unity rather than the value zero which occurs in the ground state of most molecules. This spin angular momentum adds vectorially to the angular momentum K of the "end-over-end" rotational motion of the molecule to give a total angular momentum J which may have the values $K-1$, K, or $K+1$. Transitions between these three different fine structure or ρ-type triplet levels are allowed, because of the magnetic dipole moment associated with the electron spins, with the selection rule $\Delta J=0, \pm1$. The transitions with $\Delta J=\pm1$ give a microwave absorption spectrum in the region of 60 000 Mc/sec.

Since the total orbital angular momentum of the electrons has zero component along the internuclear axis, there should be no multiplet structure of the ordinary type arising from the interaction of the electronic spin with the orbital motion of the electrons. Kramers[1] has shown that the interaction of the two unpaired electron spins, when averaged over the rotation of the molecule, is equivalent to a coupling between the total spin and the figure axis proportional to $3\cos^2\theta-1$, where θ is the angle between the two. Using this interaction and the $\mathbf{S}\cdot\mathbf{K}$ interaction between the total spin and the magnetic moment caused by the end-over-end rotation of the molecule, Kramers derived an expression for the three energy levels corresponding to $J=K+1$, K, and $K-1$.

Although the Σ-state has a zero average electronic orbital angular momentum, there is an angular momentum component perpendicular to the axis of the molecule and precessing about it. Hebb[2] considered only the interaction between this component and the total spin $S=1$ and arrived at a formula of exactly the same form as Kramers.[1] This interaction is equivalent to a perturbation of the ground state by neighboring Π-states.

In order to get satisfactory agreement between the fine structure theory and optically obtained data, Schlapp[3] recalculated the energy levels allowing for the fact that the coupling between the electron spin and the molecular rotation is appreciable compared with the rotational energy of the molecule. Schlapp's expressions for the energy differences between the members of a ρ-type triplet are:

$$\begin{aligned}\nu_+(K)&=(W_{J=K}-W_{J=K+1})/h=\lambda-\mu(K+1)\\&\quad-(2K+3)B+[\lambda^2-2\lambda B+(2K+3)^2B^2]^{\frac{1}{2}},\\\nu_-(K)&=(W_{J=K}-W_{J=K-1})/h=\lambda+\mu K+(2K-1)B\\&\quad-[\lambda^2-2\lambda B+(2K-1)^2B^2]^{\frac{1}{2}},\end{aligned}\tag{1}$$

where λ is a parameter which gives the magnitude of the interaction proportional to $\cos^2\theta$, and μ is a parameter giving the magnitude of the interaction proportional to $\cos\theta$. From this it is readily seen that

$$\nu_+(K-2)+\nu_-(K)=2\lambda+\mu,$$

where $2\lambda+\mu$ is presumably a constant.

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* Research supported jointly by the Signal Corps and the U. S. Office of Naval Research.

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[1] H. A. Kramers, Z. Physik **53**, 422 (1929).

[2] M. H. Hebb, Phys. Rev. **49**, 610 (1936).

[3] R. Schlapp, Phys. Rev. **51**, 342 (1937).

TABLE I. Tabulation of experimental and calculated frequencies, in Mc/sec, for $O^{16}O^{16}$ fine structure lines. The calculated frequencies were obtained with values $\lambda_K=59\,501.6+0.0575K(K+1)$ Mc/sec, $B_K=43\,101.6-0.14K(K+1)$ Mc/sec, and $\mu=-252.72$ Mc/sec for all values of K.

		Experimental $\nu_+(K)$			Experimental $\nu_-(K)$	
K	Calc. $\nu_+(K)$	Burkhalter	Gokhale	Calc. $\nu_-(K)$	Burkhalter	Gokhale
1	56 264.5	56 265.1	56 265.2±0.5	118 750.7	118 745.5	
3	58 446.7	58 446.2	58 446.3±0.4	62 486.4	62 486.1	62 486.2±0.4
5	59 591.2	59 610[a]		60 307.0	60 306.4	
7	60 435.1	60 436[a]		59 163.9	59 163.4	59 164.2±0.2
9	61 150.9	61 120[a]		58 323.5	58 324.0	58 324.9±0.3
11	61 800.4	61 800.2		57 612.2	57 612.0	57 612.3±0.4
13	62 411.7	62 411.7	62 412.9±0.8	56 968.3	56 968.7	
15	62 997.9	62 970[a]		56 363.0	56 362.8	56 364.2±0.5
17	63 568.1	63 568.3		55 783.7	55 784.1	
19	64 126.8	64 127.6		55 221.5	55 220.8	
21	64 677.5	64 678.9		54 671.8	54 672.5	
23	65 221.7	65 220[a]		54 131.2	54 130.0	
25	65 761.6	65 770[a]		53 597.5	53 592.2	

[a] Wave meter reading.

These transitions were observed by Beringer[4] and by Strandberg, Meng, and Ingersoll[5] at pressures near one atmosphere and therefore in an unresolved form. Burkhalter *et al.*[6] resolved the $O^{16}O^{16}$ spectrum at low pressure. They found experimentally that $\nu_+(K-2)+\nu_-(K)$ is not a constant, but varies by about one part in two thousand over twenty rotational states ($K=3$ to $K=23$). Thus no constant values of λ and μ can be found which will fit the experimental data to Schlapp's formula as it stands. Burkhalter[6] empirically fitted the data by adding $\delta K+\alpha/[K(K+1)]^{\frac{1}{2}}$ to the expression for $\nu_-(K)$, where α and δ are suitable constants.

Gokhale and Strandberg[7] have remeasured some of the $O^{16}O^{16}$ fine structure lines, and recently the $\nu_-(1)$ line, theoretically given by $2\lambda+\mu$ has been reported at 118 745.5 Mc/sec.[8] All measured frequencies for these lines are given in Table I. It may be noted that only odd K values are listed, because the zero spin of O^{16} and the fact that it obeys Bose-Einstein statistics forbid the existence of even K values.

RE-EXAMINATION OF THE FINE-STRUCTURE THEORY

It seems obvious that great care must be exercised in neglecting "small" terms in the derivation of the formula for the ρ-type triplet intervals when that formula is to be used to predict microwave absorption lines to an accuracy better than 1 Mc/sec. Inspection of Schlapp's expressions (1) indicates that second powers of μ have been omitted. Hence, as a first step in an attempt to obtain better agreement between theory and experiment, the Schlapp (Kramers) and Hebb formulas were rederived without discarding any terms.

Hill and Van Vleck[9] give the matrix elements for the $\cos^2\theta$ interaction between the spin and the figure axis. The matrix elements of the $\mathbf{S}\cdot\mathbf{K}$ interaction are easily obtained from the vector model. Therefore the energy levels arising from Kramers' interaction are the solutions of the secular determinant:

$$\begin{array}{c|ccc|}
 & K=J+1 & K=J & K=J-1 \\
K=J+1 & \begin{array}{l}2\lambda[J/(2J+1)]+B(J+1)(J+2)\\ \quad-(J+2)\mu-W\end{array} & 0 & 2\lambda[J(J+1)/(2J+1)^2]^{\frac{1}{2}} \\
K=J & 0 & 2\lambda-\mu+BJ(J+1)-W & 0 \\
K=J-1 & 2\lambda[J(J+1)/(2J+1)^2]^{\frac{1}{2}} & 0 & \begin{array}{l}2\lambda[(J+1)/(2J+1)]+BJ(J-1)\\ \quad+(J-1)\mu-W\end{array}
\end{array}=0.$$

This gives for the fine structure separations:

$$\begin{aligned}\nu_+(K)&=(W_{J=K}-W_{J=K+1})/h\\ &=\lambda-\mu(K+1)-(2K+3)(B-\tfrac{1}{2}\mu)\\ &\quad+[\lambda^2-2\lambda(B-\tfrac{1}{2}\mu)+(2K+3)^2(B-\tfrac{1}{2}\mu)^2]^{\frac{1}{2}},\end{aligned}$$

$$\begin{aligned}\nu_-(K)&=(W_{J=K}-W_{J=K-1})/h\\ &=\lambda+\mu K+(2K-1)(B-\tfrac{1}{2}\mu)\\ &\quad-[\lambda^2-2\lambda(B-\tfrac{1}{2}\mu)+(2K-1)^2(B-\tfrac{1}{2}\mu)^2]^{\frac{1}{2}}.\end{aligned}\quad(2)$$

These expressions are the same as Schlapp's formulas except for the fact that B has been replaced throughout by $B-\frac{1}{2}\mu$.

Hebb[2] gives the matrix elements connecting $^3\Pi$ and $^3\Sigma$ states in Hund's case (a). The Hebb matrix may be transformed so that the "Σ" portion is in Hund's case

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[4] R. Beringer, Phys. Rev. **70**, 53 (1946).

[5] Strandberg, Meng, and Ingersoll, Phys. Rev. **75**, 1524 (1949).

[6] Burkhalter, Anderson, Smith, and Gordy, Phys. Rev. **79**, 651 (1950).

[7] B. V. Gokhale and M. W. P. Strandberg, Phys. Rev. **84**, 844 (1951).

[8] Anderson, Johnson, and Gordy (to be published).

[9] E. L. Hill and J. H. Van Vleck, Phys. Rev. **32**, 269 (1928).

(*b*) representation. If the Van Vleck transformation[10] is then applied, the order of magnitude of the matrix elements connecting the Π and Σ states can be reduced. This leaves a "Σ" matrix of precisely the same form as that arising from the Kramers' interactions but with an additive constant in the diagonal terms. The small terms still connecting the "Π" and "Σ" matrices give contributions to the energy of higher order than λ^2. If these are neglected, the expressions for the fine structure separations derived from Hebb's interactions are thus of exactly the same form as Eq. (2), since the matrix to be solved has the same form as that for the Kramers' interaction. However, the constant λ has quite a different meaning than it does in the Kramers' expression, and the dependence of μ on other molecular parameters is evident from Hebb's treatment. If both Hebb's and Kramers' types of interaction are present, Eqs. (2) still hold, with the new constants λ and μ dependent on the sum of the two individual interactions.

COMPARISON WITH MEASURED FINE STRUCTURE

An examination of these fine structure expressions shows that $\nu_+(K-2)+\nu_-(K)$ still equals $2\lambda+\mu$. Therefore, if the theory is correct and complete, the experimental results show that $2\lambda+\mu$ must vary with K by about one part in two thousand. A small variation is not surprising, since some of the molecular parameters should change by about this amount as the molecule undergoes centrifugal distortion with increasing K. In addition, small higher order terms which have been neglected in the theory can be large enough to produce the apparent variation in $2\lambda+\mu$. These include the neglected terms in Hebb's interaction, and terms involving mixtures of singlet states resulting from the molecular rotation.

The theoretical expression for the variation in B with rotational quantum number is given by:

$$B_K=B_{K=0}-(4B^2/\omega^3)K(K+1)$$
$$=B_{K=0}-0.14K(K+1)\ \text{Mc/sec},$$

where ω is the vibrational frequency. A careful study of the experimental data for $O^{16}O^{16}$ with allowance for the change in B shows that the most reasonable fit is obtained by allowing λ to vary while μ remains constant. Excellent agreement between theory and experiment for all K values up to 25 may be obtained by assuming λ to be given by $\lambda=59\,501.6+0.0575K\times(K+1)$ Mc/sec. The variation in λ is thus of the form to be expected from centrifugal distortion, or possibly from some higher order terms. Some deviations remain for the lines corresponding to $K=1$ and 25. There is a 5 Mc/sec discrepancy in the frequency of the $\nu_-(1)$ and $\nu_-(25)$ line which is surprising, and which may warrant their remeasurement.

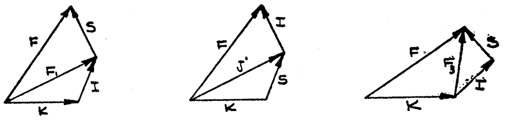

FIG. 1.

Comparisons between experimental and theoretical frequencies are given in Table I. The theoretical frequencies are calculated with $B_K=43\,101.6-0.14K\times(K+1)$ Mc/sec, $\mu=-252.72$ Mc/sec, and with λ as given above. Certain lines which are marked by an asterisk in Table I were measured experimentally only with a wavemeter and not with a frequency standard as were the other lines. Hence the errors in their measured values are as large as about 30 Mc/sec, and the theoretical values are undoubtedly considerably more accurate than the experimental ones.

ISOTOPIC SPECIES OF O_2

Formula (2) was found equally applicable to the spectrum of $O^{16}O^{18}$ and $O^{18}O^{18}$ when B and μ were varied inversely with the reduced mass of the isotopic combination as would be expected from theory. Although a number of lines of these isotopic species were observed[11] they were not measured with accuracies better than about two megacycles. Their frequencies are not given, since theoretical values are probably more accurate than these experimental measurements.

In the case of $O^{16}O^{17}$ a more complex spectrum has been observed due to a hyperfine splitting of the $O^{16}O^{17}$ fine structure lines. The hyperfine structure results from the interaction of the magnetic moment of the O^{17} nucleus with the unpaired electrons in the molecule.

MAGNETIC HYPERFINE STRUCTURE THEORY

Frosch and Foley[12] have developed a theory for magnetic hyperfine structure in diatomic molecules which is applicable to the case of $O^{16}O^{17}$. From a treatment of the problem using the two-component Pauli equation as an approximation to the Dirac equation, they have derived a perturbation Hamiltonian,

$$H=aI_zL_z+b\mathbf{I}\cdot\mathbf{S}+cI_zS_z, \tag{3}$$

where

$$a=2g_I\mu_0\mu_N(1/r^3)_{\text{Av}},$$

$$b=g_I\mu_0\mu_N\left[\frac{16\pi}{3}|\psi(0)|^2-\left(\frac{3\cos^2\chi-1}{r^3}\right)_{\text{Av}}\right],$$

$$c=3g_I\mu_0\mu_N\left(\frac{3\cos^2\chi-1}{r^3}\right)_{\text{Av}}$$

$g_I=$ the gyromagnetic ratio for the nucleus, μ_0 and μ_N are the Bohr and nuclear magnetons, respectively, r is the distance between nucleus and electron, and χ is

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[10] S. Golden and E. B. Wilson, J. Chem. Phys. **16**, 669 (1948); E. C. Kemble, *Fundamental Principles of Quantum Mechanics* (McGraw-Hill Book Company New York, 1937).

[11] Miller, Javan, and Townes, Phys. Rev. **82**, 454 (1951).

[12] R. A. Frosch and H. M. Foley, Phys. Rev. **88**, 1337 (1952).

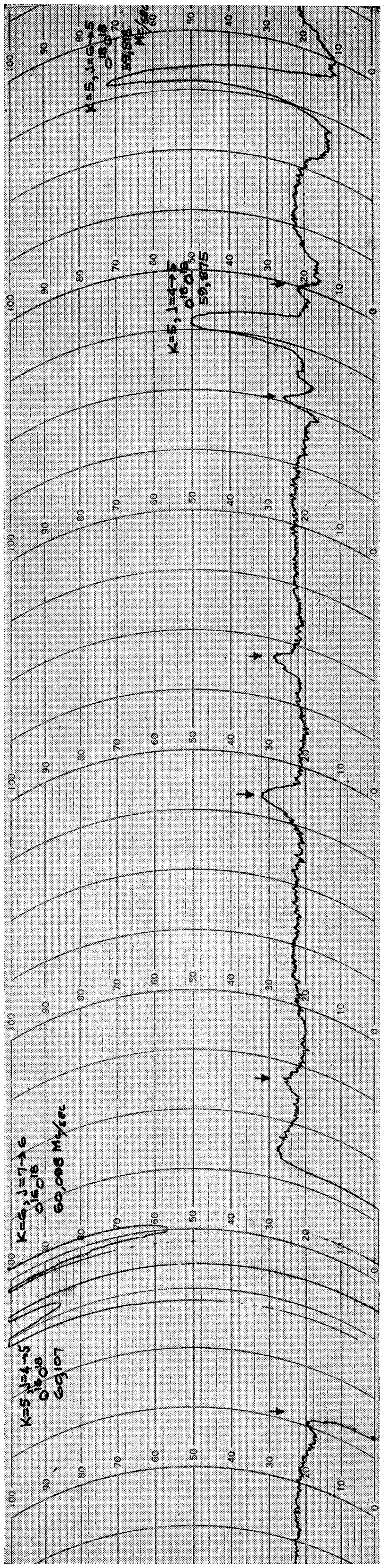

FIG. 2.

the angle between the internuclear axis and the radius vector from nucleus to electron. In a, b, and c the averages are taken over the wavefunctions of the unpaired electrons.

For a molecule in a Σ state such as O_2, $L_z=0$, so that only the terms involving b and c in (3) are of importance. It may be noted that, if the electron is spherically distributed with respect to the nucleus, the interaction (3) reduces to $b\mathbf{I}\cdot\mathbf{S}$, with $b=(16/3)\pi g_I\mu_0\mu_N|\psi(0)|^2$ as found by Fermi[13] for s electrons in an atom.

REPRESENTATION FOR $O^{16}O^{17}$

In order to find the eigenvalues of the perturbation Hamiltonian, it is important to choose a representation in which the energy is nearly diagonal. This will be achieved if a representation is chosen which is diagonal in the sum of the two vector quantities which are most tightly coupled.

There are three possible coupling schemes for I, S and K in the case of a molecule like $O^{16}O^{17}$. Vector diagrams for the three representations are shown in Fig. 1.

In $O^{16}O^{17}$ the choice of one of these simple representations is quite clear. The coupling of S to K which gives rise to the fine structure of the O_2 molecule is about 60 000 Mc/sec while the coupling between I and S which gives rise to the magnetic hyperfine structure is of the order of 100 Mc/sec. The coupling of I to K which depends on the electric quadrupole interaction is only about 3 Mc/sec, so that the second or J representation is best.

Since the choice is so clear, the contribution to the energies from off-diagonal matrix elements is very small. In this representation the perturbation Hamiltonian gives the following hyperfine structure shifts for a $^3\Sigma$ state to the first order in b and c.

$$J=K+1\quad \frac{F(F+1)-J(J+1)-I(I+1)}{2J(J+1)}\times(K+2)\left[b+\frac{c}{2K+3}\right],$$

$$J=K\quad \frac{F(F+1)-J(J+1)-I(I+1)}{2J(J+1)}(b+c),$$

$$J=K-1\quad \frac{F(F+1)-J(J+1)-I(I+1)}{2J(J+1)}\times(K-1)\left[-b+\frac{c}{2K-1}\right].$$

The terms containing the second order of b and c and the effect of nuclear quadrupole coupling were found to be negligible in this molecule.

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[13] E. Fermi, Z. Physik 60, 320 (1930).

APPARATUS AND MEASUREMENTS

The spectrum of $O^{16}O^{17}$ was observed in a sample of O_2 enriched to 1 percent abundance in O^{17}. The spectrum was measured with a recording Zeeman modulation spectrometer with a 100-kc/sec sine wave Zeeman field produced by a solenoid wound around the wave guide absorption cell. The 5-mm radiation was obtained from a Raytheon QK 295 klystron. It was necessary to cool the gas sample to liquid nitrogen temperature in order to intensify the lines enough to be detectable. Because of limitations of the frequency range of the available klystrons, the $O^{16}O^{17}$ spectrum was observed only between 59 250 Mc/sec and 60 300 Mc/sec. Figure 2 shows a portion of the recorded spectrum.

The frequencies of the observed hyperfine structure lines were determined by interpolation between $O^{16}O^{16}$, $O^{16}O^{18}$, and $O^{18}O^{18}$ fine structure lines appearing on the recorder trace. The traces taken were consistent with the assumption that expression (2) gave the frequencies of the latter lines correctly. The undisplaced positions of the $O^{16}O^{17}$ lines were assumed to be given by the same formula.

Table II lists the observed spectrum and that theoretically predicted for values of $b=-102$ Mc/sec and $c=+140$ Mc/sec. The observed and predicted relative intensities are also given. The relative intensities could be measured only very roughly because of variation in klystron power output and sample temperature. The predicted relative intensities were computed under the simplifying assumptions that all of the lines have the same width and Zeeman sensitivity. In view of this, it is felt that the relative intensities check well.

INTERPRETATION OF DATA

The B value for the $(O^{16})_2$ molecule extrapolated to the $K=0$ rotational state is 43 101.6±5 Mc/sec from the analysis of the fine structure spectrum. The internuclear distance is 1.2107A from this value of B_0. The value B_0 has also been very accurately measured by optical spectroscopy[14] to be 1.43777 ± 0.00001 cm^{-1}. Since the microwave measurement is a frequency measurement, and the optical measurement a determination of wavelength, the ratio of the microwave value of B_0 in cycles/sec to the optical value in wavenumbers affords a determination of the velocity of light. The result is $c=299\,781 \pm 33$ km/sec. This is not sufficiently accurate to be very useful, but in view of the discrepancy noted in a similar measurement involving HCN,[15] a refinement of the experimental measurements and the theory of the O_2 microwave spectrum to obtain more accuracy in the microwave value of B_0, and hence in this determination of c, may be worthwhile.

TABLE II. Tabulation of experimental and theoretical frequencies and relative intensities for $O^{16}O^{17}$ magnetic hyperfine structure lines between 59 250 Mc/sec and 60 300 Mc/sec. It is assumed that $b=-102$ Mc/sec and $c=+140$ Mc/sec for calculation of theoretical frequencies.

Transition	Frequency (Mc/sec)		Relative intensity	
	Experimental	Theoretical	Experimental	Theoretical
$K=4,\ J=5\rightarrow4,\ F=13/2\rightarrow11/2$	59 250	59 249	4	4.25
$K=7,\ J=6\rightarrow7,\ F=9/2\rightarrow11/2$	59 322	59 320	2.5	3.48
$K=5,\ J=6\rightarrow5,\ F=7/2\rightarrow5/2$	59 359	59 358	3	2.40
$K=6,\ J=5\rightarrow6,\ F=15/2\rightarrow17/2$	59 385	59 383	4.5	6.66
$K=7,\ J=6\rightarrow7,\ F=7/2\rightarrow9/2$	59 390	59 389	2.5	2.98
$K=4,\ J=5\rightarrow4,\ F=15/2\rightarrow13/2$	59 398	59 396	7	5.24
$K=5,\ J=6\rightarrow5,\ F=9/2\rightarrow7/2$	59 431	59 431	2	2.90
$K=6,\ J=5\rightarrow6,\ F=13/2\rightarrow15/2$	59 519	59 518	4	5.60
$K=5,\ J=6\rightarrow5,\ F=11/2\rightarrow9/2$		59 519		3.54
$K=5,\ J=6\rightarrow5,\ F=13/2\rightarrow11/2$	59 627	59 626	2.5	4.25
$K=6,\ J=5\rightarrow6,\ F=11/2\rightarrow13/2$	59 638	59 636	3	4.65
$K=6,\ J=5\rightarrow6,\ F=9/2\rightarrow11/2$	59 737	59 735	3	3.87
$K=5,\ J=6\rightarrow5,\ F=15/2\rightarrow13/2$	59 748	59 748	5	5.11
$K=6,\ J=7\rightarrow6,\ F=9/2\rightarrow7/2$	59 790	59 787	2.5	2.98
$K=6,\ J=7\rightarrow6,\ F=11/2\rightarrow9/2$	59 864	59 864	2.5	3.47
$K=5,\ J=6\rightarrow5,\ F=17/2\rightarrow15/2$	59 889	59 887	6	6.09
$K=6,\ J=7\rightarrow6,\ F=13/2\rightarrow11/2$	59 956	59 955	4	4.08
$K=5,\ J=4\rightarrow5,\ F=13/2\rightarrow15/2$	59 989	59 986	5.5	6.38
$K=6,\ J=7\rightarrow6,\ F=15/2\rightarrow13/2$	60 060	60 059	2	4.77
$K=5,\ J=4\rightarrow5,\ F=11/2\rightarrow13/2$	60 130	60 129		
$K=7,\ J=8\rightarrow7,\ F=11/2\rightarrow9/2$	60 170–180 (two lines)	60 172	2	3.20
$K=6,\ J=7\rightarrow6,\ F=17/2\rightarrow15/2$		60 179	3	5.55
$K=5,\ J=4\rightarrow5,\ F=9/2\rightarrow11/2$	60 240–250 (strong)	60 250	6	4.11
$K=7,\ J=8\rightarrow7,\ F=13/2\rightarrow11/2$		60 251		3.78

The theoretical hyperfine structure spectrum was computed on the basis of a nuclear spin $I=5/2$ for O^{17}. This spin value has been reported recently by Alder and Yu[16] and by Geschwind *et al.*[17] Alder and Yu found the spin from the intensity of a nuclear induction signal and Geschwind by the examination of the partially resolved quadrupole hyperfine structure of the $J=1\rightarrow2$ transition in $O^{17}CS$. The close agreement between the observed magnetic hyperfine structure and that predicted theoretically on the basis of $I=5/2$ affords an independent spin determination for O^{17} and confirms the earlier experimental results.

Experimental evaluation of the hyperfine constants b and c allows fairly direct determination of some properties of the O_2 electronic wave functions. These are discussed in the following paper.[18]

The authors wish to thank Professor A. O. Nier for supplying a sample of oxygen enriched in both O^{18} and O^{17}. They are also grateful to Messrs. A. L. Schawlow, T. M. Sanders, and W. A. Hardy who constructed the spectrometer on which the above measurements were made, and to Professor H. M. Foley and Dr. R. A. Frosch for many helpful discussions.

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[14] H. D. Babcock and L. Herzberg, Astrophys. J. **108**, 167 (1948).

[15] Rank, Ruth, and Vander Sluis, Phys. Rev. **86**, 798 (1952).

[16] F. Alder and F. C. Yu, Phys. Rev. **81**, 1067 (1951).

[17] Geschwind, Gunther-Mohr, and Silvey, Phys. Rev. **85**, 474 (1952).

[18] Miller, Townes, and Kotani, Phys. Rev. **90**, 542 (1953).

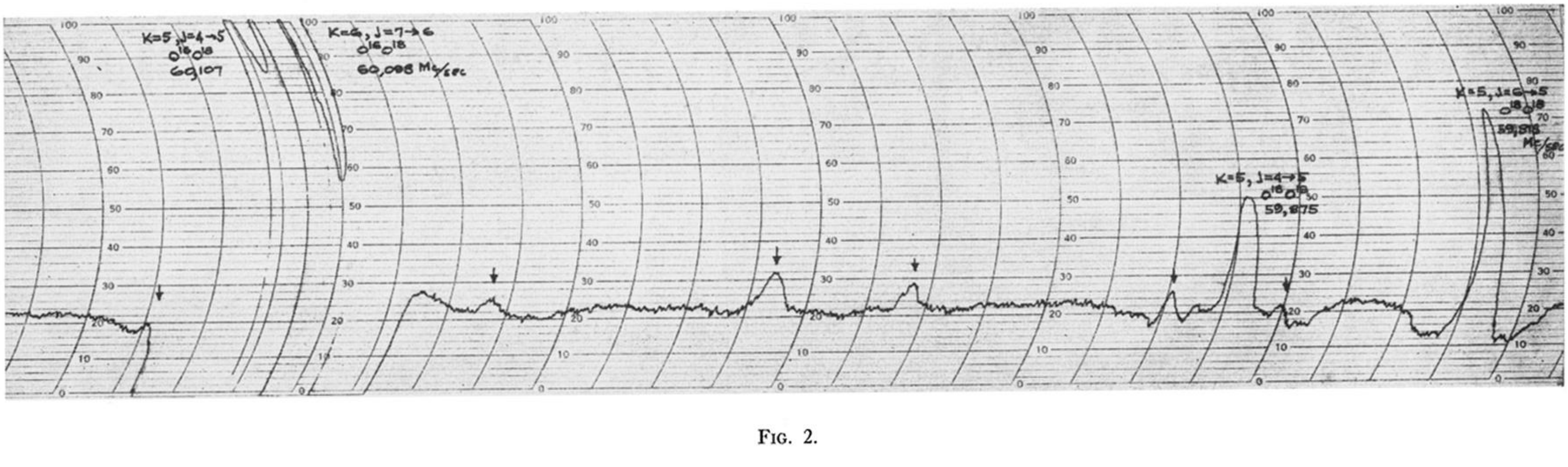
K=5, J=4→5
$O^{16}O^{18}$
60,107
K=6, J=7→6
$O^{16}O^{18}$
60,098 Mc/sec
K=5, J=4→5
$O^{16}O^{18}$
59,875
K=5, J=6→5
$O^{18}O^{18}$
59,878
Mc/sec
100
90
80
70
60
50
40
30
20
10
0

FIG. 2.