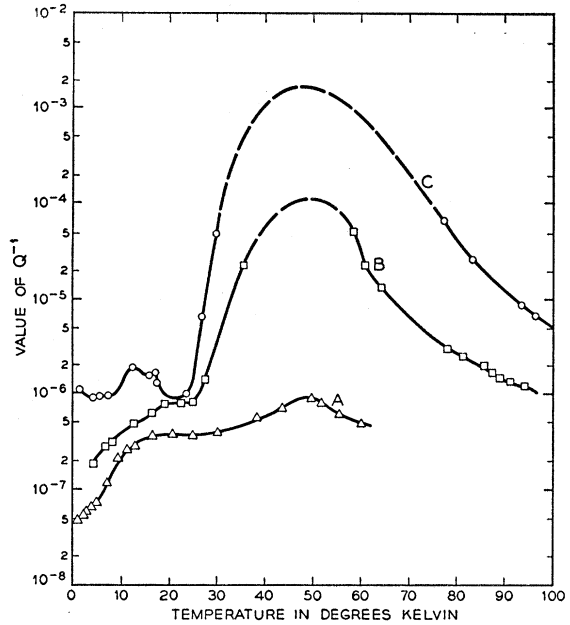

FIG. 1. Absorption of thickness shear waves at 5 Mc/sec between 1.2° and 100° Kelvin in natural quartz, curve *A*; in synthetic quartz grown on a basal-cut seed plate, curve *B*; and in synthetic quartz grown in a seed plate oriented parallel with the *z*-minor rhombohedron, curve *C*.

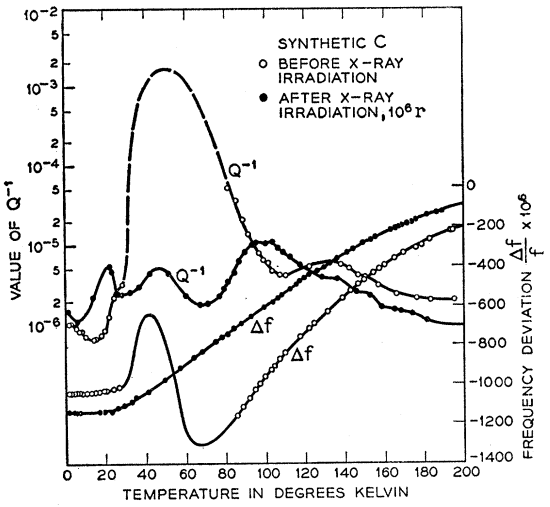

FIG. 2. Absorption of thickness shear waves and frequency deviation for a synthetic quartz (grown on a *z*-minor rhombohedron) resonator at low temperatures operating at 5 Mc/sec, before and after x-ray irradiation.

than in natural quartz. Furthermore, the incorporation of this defect in synthetic quartz grown on the *z*-minor rhombohedron is greater than in material grown on a basal cut.

In Fig. 2 may be seen the effect of stress relaxation on the frequency deviation curve over the temperature region corresponding with maximum deformation loss. This behavior is characteristic of a stress-induced relaxation process. The lower rigidity modulus of synthetic quartz at temperatures above the region of stress relaxation suggests that the defect reponsible for the deformation loss also weakens bonds in the crystal lattice. This would explain the difference observed between the frequency-temperature characteristics of *AT*-cut synthetic and natural quartz resonators.[7–9]

The effect of x-ray irradiation upon the anelasticity of synthetic quartz is also shown in Fig. 2. The irradiation has effected a two and one-half decade decrease in loss at 50°K. Coincident with this decrease in defect concentration, the frequency deviation curve becomes characteristic of natural quartz. The irradiation has also activated another relaxation loss mechanism which is maximum in the neighborhood of 100°K.

This work is continuing and the results will be published later in greater detail.

[7] Chi, Hammond, and Gerber, Proc. Inst. Radio Engrs. **43**, 1137 (1955).
[8] R. Bechmann, Proc. Inst. Radio Engrs. 44, 1600 (1956).
[9] J. C. King, Signal Corps interim reports, 1956 (unpublished).

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Stark Effect at 2.0 and 1.2 Millimeters Wavelength: Nitric Oxide

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Stark-effect measurements have been made for the first time in the 1–2 mm wave region. Results of Stark-effect measurements on the $J=\frac{1}{2}\rightarrow\frac{3}{2}$ and $J=\frac{3}{2}\rightarrow\frac{5}{2}$ transitions of the $^2\Pi_{\frac{1}{2}}$ ground state of $N^{14}O^{16}$, falling at 2.0 and 1.2 mm, respectively, are reported, and are shown to fit closely existing theory; the electric dipole moment of NO in the ground state is found to be 0.158±0.006 Debye unit.

INTRODUCTION

AT frequencies higher than 50 kMc/sec (6 mm wavelength) Stark-effect measurements have rarely been made by microwave techniques. The relatively high losses in a wave-guide absorption cell suitable for Stark modulation, coupled with the fact that only small amounts of power have been available at the higher frequencies from semiconductor crystal

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harmonic producers, has been the principal deterrent. One Stark-effect measurement, however, at 118 kMc/sec, employing square-wave modulation and phase-sensitive detection, has been reported[1] and is believed to be the highest frequency at which such an observation has been made up to the present time.

A Stark spectrometer is now in operation in this Laboratory which promises to be useful into the submillimeter wave region. So far we have made Stark-effect measurements up to 250 kMc/sec (1.2 mm), and we report here the results of such measurements on nitric oxide at both 2.0 and 1.2 mm; similar measurements on carbon monoxide at 2.7 mm and deuterium iodide at 1.5 mm have been completed and are being reported elsewhere.

Nitric oxide is unusual among stable molecules in that it has both nonzero electron spin and angular momentum in the ground state. The ground electronic state is $^2\Pi_{\frac{1}{2}}$, but the $^2\Pi_{\frac{3}{2}}$ state lies only 124 cm^{-1} above it, and is appreciably populated at room temperature. The lowest rotational transitions, $J=\frac{1}{2}\rightarrow\frac{3}{2}$ and $J=\frac{3}{2}\rightarrow\frac{5}{2}$, each have two components due to Λ doubling. Since the nitrogen nucleus has a spin of 1, the molecule has a nuclear magnetic moment as well as a nuclear electric quadrupole moment, and hyperfine structure arises from the interaction of these moments with the molecular magnetic and electric fields, further splitting the Λ-doubling components. The resulting rotational spectrum is composed of two groups of five lines each for the $J=\frac{1}{2}\rightarrow\frac{3}{2}$ transition, and two groups of six lines each for the $J=\frac{3}{2}\rightarrow\frac{5}{2}$ transition, as has been observed in the microwave spectrum by several workers.[2]

Recently Mizushima[3] has made theoretical predictions concerning the Stark effect in the NO molecule, and we have now measured the effect in the two lowest rotational transitions, $J=\frac{1}{2}\rightarrow\frac{3}{2}$ and $J=\frac{3}{2}\rightarrow\frac{5}{2}$, of the $^2\Pi_{\frac{1}{2}}$ ground state, which fall at 2.0 and 1.2 mm, respectively.

APPARATUS AND MEASUREMENT

The stark spectrometer was of the conventional type,[4] with a one-meter absorption cell of K-band wave guide carrying a Teflon-insulated metal septum. A dc voltage was applied to the septum to produce an electric field parallel to the microwave electric field.

Power at 2.0 and 1.2 mm was generated by a crossed-wave-guide crystal harmonic producer of the general type described by King and Gordy,[5] driven by a Raytheon 2K33 klystron operating at about 25 kMc/sec and frequency modulated at 60 cps. The silicon crystals used in the harmonic producer were of a considerably improved variety produced in these laboratories by R. S. Ohl. The detected signal was amplified by an audio amplifier employing a modified cascode input stage with a 5-megohm input impedance, and the absorption lines were displayed on a cathode-ray tube screen. Wave-guide sections with constrictions at least 2–3 wavelengths long were used as high-pass filters to prevent passage of lower frequency harmonics and thus reduce the otherwise excessive noise at the crystal detector.

Frequency measurements were made with a secondary frequency standard monitored by station WWV at 5 Mc/sec; dc voltage measurements were made at the Stark cell with a Simpson model 262 voltmeter which had been recalibrated to an accuracy of about one-half percent.

The effective electrode spacing in the Stark cell was determined by measurement of the Stark effect in HCN. The electric dipole moment of this molecule has been determined by microwave measurements of the Stark effect in the $J=0\rightarrow1$ transition at 88.6 kMc/sec, and the value of μ thus obtained is 3.00 ± 0.02 Debye units.[6,7] In the calibration process, which was carried out at dry-ice temperatures both before and after the NO measurements, frequency shifts up to 129 Mc/sec were observed. The splitting in the $J=0\rightarrow1$ transition of HCN due to the electric quadrupole moment of the nitrogen nucleus is small (a fraction of a Mc/sec for the component used) and thus a strong-field case was assumed; the effective electrode spacing was then obtained from the slope of the $\Delta\nu$ *vs* E^2 plot.

Stark splittings of the strongest lines in NO were measured at both dry-ice and liquid-nitrogen temperatures, but it was necessary to use liquid-nitrogen temperatures in order to observe adequately the splittings of the weaker lines. A very small correction in the electrode spacing (0.2%) was occasioned by this necessity of making part of the measurements at liquid-nitrogen temperature.

Figure 1 shows a photograph of oscilloscope tracings of some of the lines as observed at 1.2 mm both with and without a Stark electric field.

THEORY

Since the rotational spectrum of nitric oxide is complicated by hyperfine structure, calculation of the Stark-effect perturbations is somewhat more complicated than for the usual diatomic molecule. Recently, however, Mizushima[3] has made theoretical

[1] Trambarulo, Ghosh, Burrus, and Gordy, J. Chem. Phys. **21**, 851 (1953).

[2] C. A. Burrus and W. Gordy, Phys. Rev. **92**, 1437 (1953); Gallagher, Bedard, and Johnson, Phys. Rev. **93**, 729 (1954); Mizushima, Cox, and Gordy, Phys. Rev. **98**, 1034 (1955); J. J. Gallagher and C. M. Johnson, Phys. Rev. **103**, 1727 (1956).

[3] M. Mizushima, Phys. Rev. **109**, 1557 (1958), following paper.

[4] See, for example, Gordy, Smith, and Trambarulo, *Microwave Spectroscopy* (John Wiley and Sons, Inc., New York, 1953).

[5] W. C. King and W. Gordy, Phys. Rev. **90**, 319 (1953).

[6] Ghosh, Trambarulo, and Gordy, J. Chem. Phys. **21**, 308 (1953).

[7] At the 1957 American Physical Society meeting in Washington, D. C., Bhattacharya, Gordy, and Fujii [Bull. Am. Phys. Soc. Ser. II, **2**, 213 (1957)] reported preliminary results of precision measurements of the dipole moment of HCN. Their tentative value is $\mu=2.986\pm0.002$ Debye units. If this value is taken for calibration instead of 3.00, our value of μ for NO will be lowered by about $\frac{1}{2}$ percent.

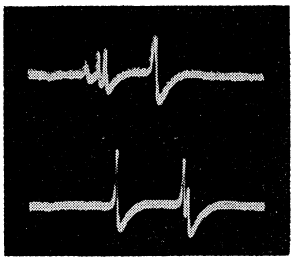


FIG. 1. Photograph of oscilloscope tracings of the three high-ν lines of the ν^d (upper) group of the $J=\frac{3}{2}\rightarrow\frac{5}{2}$ transition of the $^2\Pi_{\frac{1}{2}}$ ground state of nitric oxide. Lower tracing: Stark field=0; upper tracing, Stark field=6000 v/cm. The wavelength is 1.2 mm, and the greatest frequency shift shown is about 9 Mc/sec.

predictions, for both the strong- and weak-field cases, of the ground-state energy level perturbations to be expected from the application of an external dc electric field to the NO molecule.

For the weak-field approximation, where the Stark-effect perturbations are small compared to the hyperfine separations, and where the effect is second order, the energy level perturbations are given by Mizushima as

$$W(cJFM_F) = -\frac{2.27925\times10^4\mu^2E^2}{16J^2(J+1)^2}\times\left\{M_F^2\frac{[J(J+1)+F(F+1)+2]^2}{(W_{dJF}{}^0-W_{cJF}{}^0)F^2(F+1)^2}+(F^2-M_F^2)\times\frac{(F+J+2)(J-F+2)(F-J+1)(J+F-1)}{(W_{dJF-1}{}^0-W_{cJF}{}^0)F^2(2F+1)(2F-1)}+[(F+1)^2-M_F^2]\times\frac{(F+J+3)(J-F+1)(F-J+2)(J+F)}{(W_{dJF+1}{}^0-W_{cJF}{}^0)(F+1)^2(2F+3)(2F+1)}\right\}+W'(cJFM_F), \quad (1)$$

where μ is the electric dipole moment in Debye units, E is the applied electric field in esu/cm, and the energy W is in Mc/sec. The subscript c is used to designate the lower frequency component of the Λ doublet and the subscript d denotes the higher frequency component. The factor 2.27925×10^4 is necessary for conversion to the units used here, and the last term, $W'(cJFM_F)$, arises from nondiagonal matrix elements between different J values; it is assumed to be small.[3] $W(dJFM_F)$ may be evaluated by an interchange of c and d in Eq. (1).

The zero-field energy levels are given by[8]

$$W_{\alpha JF'}{}^0=W_J\pm W_{\alpha\Delta J}+W_{\alpha JF'}+\Delta W_{\alpha JF'}+W_{\alpha JF'}{}'+\Delta W_{\alpha JF'}', \quad (2)$$

where $\alpha=c$ or d and $F'=F-1$, F, $F+1$. W_J is the rotational energy, and $W_{\alpha\Delta J}$ gives the Λ-doubling energy with the (+) and (−) signs corresponding to the d and c states, respectively. $W_{\alpha JF'}$ is the magnetic hyperfine energy, $\Delta W_{\alpha JF'}$ arises from mixing of the rotational levels in the $^2\Pi_{\frac{1}{2}}$ ground state and the nearby $^2\Pi_{\frac{3}{2}}$ state, $W_{\alpha JF'}{}'$ is the nuclear electric quadrupole interaction energy, and $\Delta W_{\alpha JF'}{}'$ is a "pseudo-quadrupole" term resulting from a magnetic interaction between the $^2\Pi_{\frac{1}{2}}$ and $^2\Pi_{\frac{3}{2}}$ states; these are evaluated in reference 8.

[8] M. Mizushima, Phys. Rev. **94**, 569 (1954); C. C. Lin and M. Mizushima, Phys. Rev. **100**, 1726 (1955).

TABLE I. Calculated energy level shift in an electric field for the $^2\Pi_{\frac{1}{2}}$ state of $N^{14}O^{16}$.[a]

J	State F	M_F	$k_c(JFM_F)$	$k_d(JFM_F)$
$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	6.858_3	-11.370_2
$\frac{1}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	10.652_8	-6.140_9
$\frac{1}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	5.886_2	-5.886_2
$\frac{3}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0.863_1	-0.885_6
$\frac{3}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	0.659_7	-0.655_1
$\frac{3}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	0.882_2	-0.894_1
$\frac{3}{2}$	$\frac{5}{2}$	$\frac{1}{2}$	0.255_9	-0.238_1
$\frac{3}{2}$	$\frac{5}{2}$	$\frac{3}{2}$	0.550_3	-0.538_4
$\frac{3}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	1.139_0	-1.139_0
$\frac{5}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	0.0811_9	-0.0823_3
$\frac{5}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	0.380_7	-0.381_5
$\frac{5}{2}$	$\frac{5}{2}$	$\frac{1}{2}$	0.0845_9	-0.0845_3
$\frac{5}{2}$	$\frac{5}{2}$	$\frac{3}{2}$	0.179_4	-0.179_5
$\frac{5}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	0.368_9	-0.369_5
$\frac{5}{2}$	$\frac{7}{2}$	$\frac{1}{2}$	0.0364_9	-0.0354_1
$\frac{5}{2}$	$\frac{7}{2}$	$\frac{3}{2}$	0.0971_3	-0.0962_3
$\frac{5}{2}$	$\frac{7}{2}$	$\frac{5}{2}$	0.218_4	-0.217_9
$\frac{5}{2}$	$\frac{7}{2}$	$\frac{7}{2}$	0.400_3	-0.400_3

[a] The energy level shift is the coefficient k_α ($\alpha=c,d$) multiplied by $-\mu^2E^2$.

The expression for the weak-field Stark perturbation energy may be reduced to

$$W(\alpha JFM_F)=-[k_\alpha(JFM_F)]\mu^2E^2. \quad (3)$$

Numerical values of $k_\alpha(JFM_F)$ have been calculated for the $J=\frac{1}{2}$, $\frac{3}{2}$, and $\frac{5}{2}$ levels of the $^2\Pi_{\frac{1}{2}}$ ground state and are tabulated in Table I.

When the electric Stark field and the microwave electric field are parallel, the allowed transitions are given by $\Delta J=1$, $\Delta F=0$, ±1, $\Delta M_F=0$. The Stark splitting of a given transition is then, from Eq. (3):

$$W(\alpha J'F'M_F)-W(\alpha JFM_F)=-[k_\alpha(J'F'M_F)-k_\alpha(JFM_F)]\mu^2E^2, \quad (4)$$

or

$$\Delta\nu^\alpha(J\rightarrow J',F\rightarrow F',M_F\rightarrow M_F)=-[\Delta k_\alpha(J\rightarrow J',F\rightarrow F',M_F\rightarrow M_F)]\mu^2E^2, \quad (5)$$

where the unprimed letters refer to the lower of the transitions involved.

For a second-order Stark effect the electric dipole moment, μ, may be determined from a plot of the experimental values of $\Delta\nu^\alpha$ *vs* E^2. From Eq. (5) it is seen that the slope, $S^\alpha(J\rightarrow J',F\rightarrow F',M_F\rightarrow M_F)$, of such a curve is $[\Delta k_\alpha(J\rightarrow J',F\rightarrow F',M_F\rightarrow M_F)]\mu^2$ and thus the electric dipole moment is given by

$$\mu=\left[\frac{S^\alpha(J\rightarrow J',F\rightarrow F',M_F\rightarrow M_F)}{\Delta k_\alpha(J\rightarrow J',F\rightarrow F',M_F\rightarrow M_F)}\right]^{\frac{1}{2}}. \quad (6)$$

TABLE II. Calculated stark splittings and observed stark splittings and dipole moment of the $^2\Pi_{\frac{1}{2}}$ state of $N^{14}O^{16}$.

Transition Lower state J	F	M_F	Upper state J	F	M_F	Frequency (Mc/sec) lower group of doublet	Slope[a] Observed	Slope[a] Calculated	Dipole[b] moment (Debye unit)	Frequency (Mc/sec) upper group of doublet	Slope[a] Observed	Slope[a] Calculated	Dipole[b] moment (Debye unit)
$\frac{1}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	$\frac{5}{2}$	$\frac{1}{2}$	150 176.54	0.259_3	0.260_2	0.157_9	150 546.54	-0.143_0[c]	-0.147_7	0.155_7
$\frac{1}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	$\frac{5}{2}$	$\frac{3}{2}$	150 176.54	0.129_7	0.133_5	0.155_9	150 546.54		-0.133_8	0.163_5
$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	150 198.85	0.157_3	0.155_1	0.159_3	150 644.34	-0.266_0	-0.268_2	0.157_6
$\frac{1}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	150 218.81	[d]	0.249_9		150 439.07	[e]	-0.137_3	
$\frac{1}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	150 218.81	0.127_7	0.125_2	0.159_8	150 439.07	-0.126_7	-0.124_9	0.159_3
$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	150 225.68	0.148_3	0.150_0	0.157_3	150 580.63	-0.265_0	-0.262_4	0.159_0
$\frac{1}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	150 245.72	0.245_3	0.245_0	0.158_3	150 375.03	-0.133_0	-0.131_5	0.159_1
$\frac{3}{2}$	$\frac{5}{2}$	$\frac{1}{2}$	$\frac{5}{2}$	$\frac{7}{2}$	$\frac{1}{2}$	250 437.03	0.0569_3	0.00549_2	0.161_1	250 796.51	-0.00547_1	-0.0507_1	0.164_3
$\frac{3}{2}$	$\frac{5}{2}$	$\frac{3}{2}$	$\frac{5}{2}$	$\frac{7}{2}$	$\frac{3}{2}$	250 437.03	0.0123_3	0.0113_4	0.165_0	250 796.51	-0.0122_4	-0.0110_7	0.166_4
$\frac{3}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	$\frac{7}{2}$	$\frac{5}{2}$	250 437.03	0.0233_3	0.0230_4	0.159_2	250 796.51	-0.0230_7	0.0230_5	0.158_3
$\frac{3}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	$\frac{1}{2}$	250 440.82	[e]	0.0143_9		250 815.69	-0.0145_3	-0.0142_8	0.159_6
$\frac{3}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	$\frac{3}{2}$	250 440.82	0.0166_5	0.0178_9	0.152_6	250 815.69	-0.0176_0	-0.0178_8	0.156_9
$\frac{3}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	250 448.70	0.0187_3	0.0195_7	0.154_8	250 817.01	-0.0192_5	-0.0201_0	0.154_8
$\frac{3}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	$\frac{5}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	250 475.56	[e]	0.0144_8		250 753.20	[e]	-0.0143_3	
$\frac{3}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	$\frac{5}{2}$	$\frac{3}{2}$	$\frac{3}{2}$	250 475.56	0.0116_0	0.0125_5	0.152_1	250 753.20	-0.0125_1	-0.0128_3	0.156_2
$\frac{3}{2}$	$\frac{5}{2}$	$\frac{1}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	$\frac{1}{2}$	250 483.10	[e]	0.00429_1		250 708.48	[e]	-0.00384_4	
$\frac{3}{2}$	$\frac{5}{2}$	$\frac{3}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	$\frac{3}{2}$	250 483.10	[e]	0.00928_2		250 708.48	-0.00920_2	-0.00898_2	0.160_1
$\frac{3}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	250 483.10	0.0191_9	0.0192_7	0.157_9	250 708.48	-0.0188_4	-0.0192_6	0.156_5

[a] Calculated using $\mu=0.158_2$ Debye units.
[b] Calculated from the observed slope.
[c] Line quite broad but never split into resolvable components.
[d] Insufficient experimental data to obtain slope.
[e] Weak transition not observed.

RESULTS

Microwave measurements of frequency shift *vs* applied field in NO show that the Stark effect is second order up to fields of approximately 5 esu/cm (1500 v/cm) for the $J=\frac{1}{2}\rightarrow\frac{3}{2}$ transition, and up to approximately 16 esu/cm (4800 volts/cm) for the $J=\frac{3}{2}\rightarrow\frac{5}{2}$ transition. At higher fields, up to 25 esu/cm (7500 v/cm), there was considerable but consistent deviation from the $\Delta\nu\propto E^2$ relation, indicating that the weak field approximation is no longer valid.

Of the expected Stark components in the $J=\frac{1}{2}\rightarrow\frac{3}{2}$ transition, only one was too weak to be observed with video detection at 2 mm. At 1.2 mm, the $F=\frac{5}{2}\rightarrow\frac{3}{2}$ hyperfine component of the $J=\frac{3}{2}\rightarrow\frac{5}{2}$ transition, with a relative intensity of 0.5, was not observed. Of the remaining possible 22 Stark components, only 6 were too weak to be seen with video detection. These data thus include measurements on many components,

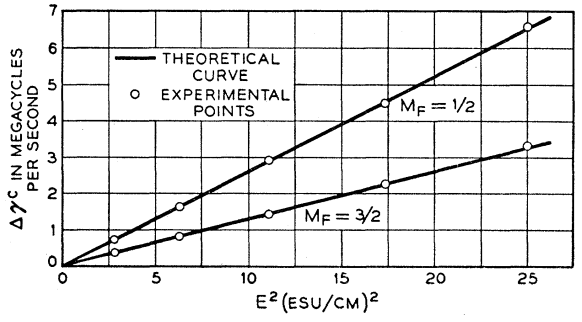


FIG. 2. Representative plot of the experimental data from which the electric dipole moment was calculated. Shown is the $J=\frac{1}{2}\rightarrow\frac{3}{2}$, $F=\frac{3}{2}\rightarrow\frac{5}{2}$ transition at 2 mm. The theoretical curves were plotted using appropriate values of $k_\alpha(JFM_F)$ from Table I and $\mu=0.158_2$ Debye unit.

and the very good agreement between theory and experiment may be seen from a comparison of the experimental and calculated slopes of the $\Delta\nu$ *vs* E^2 curves, which are tabulated for all observed transitions in Table II. A representative plot of $\Delta\nu$ *vs* E^2 for one $F\rightarrow F'$ transition is shown in Fig. 2; the usual intensity rules have been used to identify the components.

The electric dipole moment was evaluated from all observable components of both the $J=\frac{1}{2}\rightarrow\frac{3}{2}$ and the $J=\frac{3}{2}\rightarrow\frac{5}{2}$ transitions. Plots of $\Delta\nu$ *vs* E^2, the tabulated values of k_α from Table I, and Eq. (6) were used in the calculations. The values thus obtained from each of the individual Stark components are tabulated in Table II, and an average of the results gives

$$\mu=0.158\pm0.006 \text{ Debye unit}$$

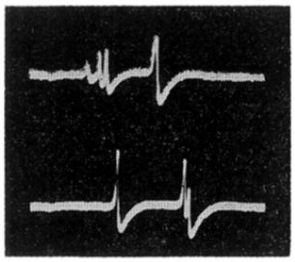
for nitric oxide.

Values of μ for NO have been obtained previously by calculation from measurements of the dielectric constant, and are given as 0.16 Debye unit by Watson *et al.*[9] and as 0.07 Debye unit by Smyth and McAlpine.[10] Watson's value of 0.16 Debye unit is seen to be in excellent agreement with our present microwave value of 0.158 Debye unit.

ACKNOWLEDGMENTS

We wish to thank Dr. M. Mizushima for sending us his work on the theory of the Stark effect in NO which led us to undertake this measurement; Mr. R. S. Ohl for the specially prepared silicon crystals; and Dr. R. F. Trambarulo for helpful discussions. Mr. R. D. Bahrs assisted in taking the data.

[9] Watson, Rao, and Ramaswamy, Proc. Roy. Soc. (London) **A143**, 558 (1934).
[10] C. P. Smyth and K. B. McAlpine, J. Chem. Phys. **1**, 60 (1933).



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