plate. It is required that the shock velocity obtained from this "transit time" be consistent with one predicted from compressibility data. It should be noted that the pins on the NaCl and Teflon samples eventually discharge also. The timing of this phenomenon easily distinguishes this as being due to the arrival of the aluminum plate itself. Table I compares the results of experiments with known values of the shock velocity.

Further experiments are in progress to try to determine the precise pressure at which the metallic transition occurs for these and other crystals, its temperature dependence, and the nature of any volume change associated with the transition.

[1] See for example, Goranson, Bancroft, Burton, Blechar, Houston, Gittings, and Landeen, J. Appl. Phys. **26**, 1472 (1955).
[2] The $LiAlH_4$ might have contained a fair amount of metallic aluminum as an impurity, as evidenced by its grayish appearance.
[3] J. M. Walsh and R. H. Christian, Phys. Rev. **97**, 1544 (1955).

## Further Extension of Microwave Spectroscopy in the Submillimeter Wave Region*

MONROE COWAN AND WALTER GORDY
*Department of Physics, Duke University, Durham, North Carolina*
(Received August 28, 1956)

EARLIER developments in this laboratory led to the extension of microwave measurements through the shortest millimeter waves[1] and into the submillimeter range[2] to wavelengths of 0.77 mm. The present work extends further the reach of microwave electronic methods to wavelengths as short as 0.587 mm. Rotational lines of OCS have been observed with an automatic pen-and-ink recorder through the $J=41\rightarrow42$ transition at 510 457.3 Mc/sec. They have been seen on the cathode-ray scope to wavelengths of 0.685 mm (Fig. 1).

The $J=0\rightarrow1$ transition of hydrogen iodide has been measured in the 0.778-mm region. Table I summarizes the results. Figure 2 is a cathode-ray display of two components of the triplet $I^{127}$ hyperfine structure. The nuclear magnetic coupling constant, $C_I$, of $I^{127}$ is approximately twice that[1] in DI; the nuclear quadrupole coupling and $r_0$ are slightly greater than those for DI. The moment of inertia of hydrogen iodide is the smallest to be measured with microwave methods.

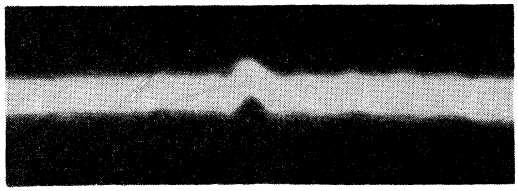



FIG. 1. Cathode-ray display of a spectral line at 0.685-mm wavelength, or 486 184.2 Mc/sec frequency; the $J=35\rightarrow36$ transition of OCS obtained with the 18th harmonic energy from a 2K33 klystron. The line width is about 1 Mc/sec.

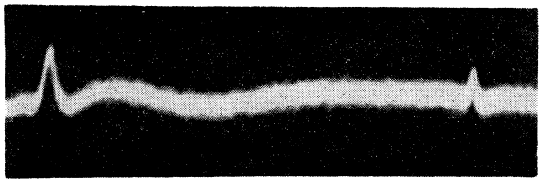
Several investigators have studied the infrared spectrum of this molecule. Czerny[3] in 1927 measured pure rotational lines of HI in the 0.1-mm region. The near-infrared value of $B_0$ by Boyd and Thompson[4] agrees with ours to the four figures which they quote.

The $J=2\rightarrow3$ line of $C^{12}O^{16}$ (Fig. 3) has been measured in the 0.867-mm region at 345 802 Mc/sec. With the multiple harmonic method previously described,[1] the first three rotational lines of CO were seen on the scope together, and their separations caused by centrifugal stretching were measured directly. The stretching constant thus obtained is 0.1888 Mc/sec, in agreement with the value obtained for the lower-$J$ millimeter wave transitions.[5] By further measurements on these frequencies and by measurement of the $J=3\rightarrow4$ line at 0.65 mm, we hope later to improve the accuracy of both $B_0$ and $D_0$. The earlier millimeter wave measurements[5,6] on CO have already been used in a preliminary infrared-microwave evaluation of the velocity of light by Plyler, Blaine, and Connor.[7]

The experimental methods and designs of the harmonic generator and detector are the same as those for the earlier work.[1,2] As before, the source of submillimeter wave power is a silicon crystal harmonic generator driven by a Raytheon centimeter wave klystron (2K33). Harmonics up to the 21st were detected. The multiplier crystal was one supplied to us by R. S. Ohl, of the Bell Telephone Laboratories. It was noticeably better for harmonic generation than were the commercial varieties used in the earlier work. We wish to than Mr. Ohl for this considerable favor. For detection we have continued to use sections of crystals obtained from Sylvania Electric Company. Frequency measurements were made with a secondary standard monitored by the 5-Mc frequency of Station WWV.

TABLE I. Observed and calculated frequencies of $HI^{127}$. $J=0\rightarrow1$, $\nu_0=385\,293.27\pm0.70$ Mc/sec.

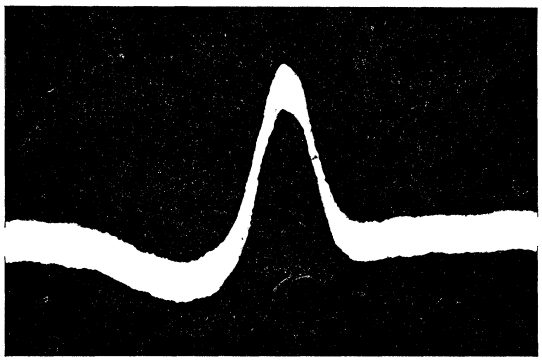
| Transition $F\rightarrow F'$ | Relative intensity | Quadrupole displacement (Mc/sec) first order | Quadrupole displacement (Mc/sec) second order | Magnetic displacement (Mc/sec) | Calculated frequency (Mc/sec) | Observed frequency (Mc/sec) |
|---|---|---|---|---|---|---|
| $5/2\rightarrow5/2$ | 75 | −292.96 | 0.07 | −0.26 | 385 000.12 | 385 000.11±0.70 |
| $5/2\rightarrow7/2$ | 100 | 91.55 | 0.05 | 0.65 | 385 385.52 | 385 385.52±0.70 |
| $5/2\rightarrow3/2$ | 50 | 256.34 | 0.09 | −0.91 | 385 548.79 | 385 548.80±0.70 |



λ = 0.78 mm

FIG. 2. Cathode-ray display of two of the three hyperfine components of the $J=0 \rightarrow 1$ transition of HI at 0.778-mm wavelength. The line to the left is the $F=5/2 \rightarrow 7/2$ component, and the one to the right is the $F=5/2 \rightarrow 3/2$ component. These two components observed on the same scope trace are 163.3 Mc/sec apart. The klystron mode would not cover all three components in a single sweep.

With the klystron harmonic method, high precision and high resolution together with convenient frequency sweep and automatic display spectroscopy are, in



λ = 0.87 mm

FIG. 3. Cathode-ray display of the $J=2 \rightarrow 3$ transition of $C^{12}O^{18}$ at 0.867-mm wavelength (345 802 Mc/sec). The line width is about 1 Mc/sec.

effect, achieved as soon as usuable harmonic power can be detected. The signal-to-noise ratio obtainable in the submillimeter region with a low-power, centimeter-wave klystron as the primary source is indeed remarkable.

TABLE II. Molecular constants[a] of $HI^{127}$.

| | |
|---|---|
| $eqQ(I^{127}) = 1831.0 \pm 1.0$ | $C_I(I^{127}) = 0.26$ Mc/sec |
| $B_0 = 192\,658.6$ Mc/sec | $r_0 = 1.61970$ A |
| $B_e = 195\,229.1$ Mc/sec | $r_e = 1.60904$ A |

[a] The infrared values of $D_0 = 0.00020$ cm$^{-1}$ and $\alpha = 0.1715$ cm$^{-1}$ from Boyd and Thompson[4] are used in the calculation of $B$ and $r$. Atomic constants are from J. W. M. DuMond and E. R. Cohen, Revs. Modern Phys. 25, 691 (1953).

With the same klystrons six years ago we were pleased, even excited, to generate usable harmonic power in the 3- to 4-millimeter wave region.

* This research was supported by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.

[1] W. C. King and W. Gordy, Phys. Rev. **90**, 319 (1953); **93**, 407 (1954). C. A. Burrus and W. Gordy, Phys. Rev. **92**, 274 (1953); **92**, 1437 (1953).
[2] C. A. Burrus and W. Gordy, Phys. Rev. **93**, 897 (1954); **101**, 599 (1956).
[3] M. Czerny, Z. Physik **44**, 235 (1927).
[4] R. D. Boyd and R. J. Thompson, Spectrochim. Acta **5**, 308 (1952).
[5] Bedard, Gallagher, and Johnson, Phys. Rev. **92**, 1440 (1953).
[6] Gilliam, Johnson, and Gordy, Phys. Rev. **78**, 140 (1950).
[7] Plyler, Blaine, and Connor, J. Opt. Soc. Am. **45**, 102 (1955).

## Magnetic Domains in Thin Films by the Faraday Effect*

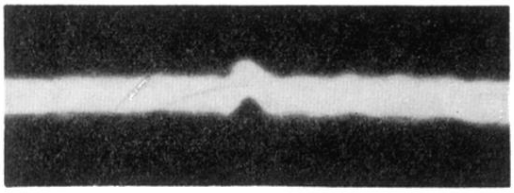
CHARLES A. FOWLER, JR., AND EDWARD M. FRYER
*Department of Physics, Pomona College, Claremont, California*
(Received August 30, 1956)

THE Kerr magneto-optic technique has proved well suited for photographing magnetic domains in evaporated thin films of ferromagnetic material, but the method begins to lose effectiveness for films thin enough to be transparent, principally because of the decreased intensity of the reflected light.[1] Inasmuch as the loss of reflected intensity is accompanied by an increase in the transmitted light, utilizing the magnetic rotation of the polarization in the transmitted beam (Faraday effect) naturally suggests itself. If the domains lie parallel to the film surface, no rotation will occur for the perpendicular passage of a polarized beam, but for oblique transmission a rotation proportional to the component of magnetization along the transmitted beam should develop.

To test the idea, we have accordingly made the obvious modifications in our Kerr reflection arrangement[2] in order to make observation by direct transmission possible, i.e., aligned on a single optical bench the source, collimator lens, polarizer, specimen, analyzer, and camera. The specimen was a NiFe film (80% nickel) of 500 angstrom thickness whose domain behavior we had previously investigated by the reflection technique. This film prefers to exist as a single domain, but it will occasionally develop multiple domain structure if carefully disturbed with a coercing field.

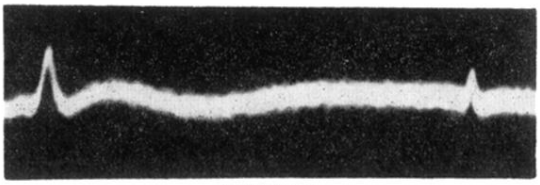
With the film surface normal to the incident beam, magnetization reversals caused no measurable rotation of the polarization plane as observed with the photocell monitor, but with oblique passage of the light a Faraday rotation associated with the magnetization reversal appeared, its magnitude increasing with the obliquity. Inasmuch as the difficulty of satisfactorily photographing the entire surface also increases with obliqueness, we set the angle at 45°. For this angle the Faraday rotation accompanying a reversal of magnetization amounted to about 9 minutes, a value sufficiently large to reveal adjacent domains photographically.

Figure 1 shows two photographs of the 500-angstrom specimen in the same partially magnetized state, the upper picture taken in reflection by the Kerr method, the lower photograph obtained in transmission by the Faraday effect. The improvement in sharpness, in



$\lambda = 0.68$ mm

FIG. 1. Cathode-ray display of a spectral line at 0.685-mm wavelength, or 486 184.2 Mc/sec frequency; the $J = 35 \rightarrow 36$ transition of OCS obtained with the 18th harmonic energy from a 2K33 klystron. The line width is about 1 Mc/sec.



$\lambda = 0.78$ mm

FIG. 2. Cathode-ray display of two of the three hyperfine components of the $J=0 \rightarrow 1$ transition of HI at 0.778-mm wavelength. The line to the left is the $F=5/2 \rightarrow 7/2$ component, and the one to the right is the $F=5/2 \rightarrow 3/2$ component. These two components observed on the same scope trace are 163.3 Mc/sec apart. The klystron mode would not cover all three components in a single sweep.