Professor J. Lindhard of Aarhus University for pointing out the importance of the equipartition rule in interpreting the energy shifts.

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18-cm SPECTRUM OF OH†

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The detection of interstellar OH by its 18-cm absorption spectrum[1-3] has created a need for improved laboratory measurements of the spectrum. Earlier measurements of the line frequencies, although invaluable for locating and identifying the interstellar spectrum in the first place, are too coarse to use in analyses of the observational results. An experimental accuracy of about one part per million in the rest frequencies is required for evaluation of Doppler shifts, and measurements to this accuracy are reported here.

The spectrum consists of four electric dipole transitions within the Λ-type doublet structure of the molecular ground state. The line frequencies are approximately 1612, 1665, 1667, and 1720 MHz (Mc/sec), with expected relative intensities of 1:5:9:1. In a weak magnetic field, such as the earth's field, each of the two stronger lines ($\Delta F = 0$) splits into a normal Zeeman triplet, consisting of one π component ($\Delta M_F = 0$) and two oppositely shifted σ components ($\Delta M_F = \pm 1$). The same field splits each of the two weak lines ($\Delta F = \pm 1$) into three π components and six σ components; this is illustrated by Fig. 1, which is a recording of the 1612-MHz line made in the earth's magnetic field. These splitting patterns are not quite symmetrical about the line positions at zero field, the chief reasons being the small difference between the molecular magnetic moments of the upper and lower Λ-type doublet levels, and the presence of quadratic Zeeman shifts. Both of these effects are small, typically 1 kHz or less in the earth's field; they may be calculated reliably, and introduce no uncertainty in the determination of zero-field frequencies.

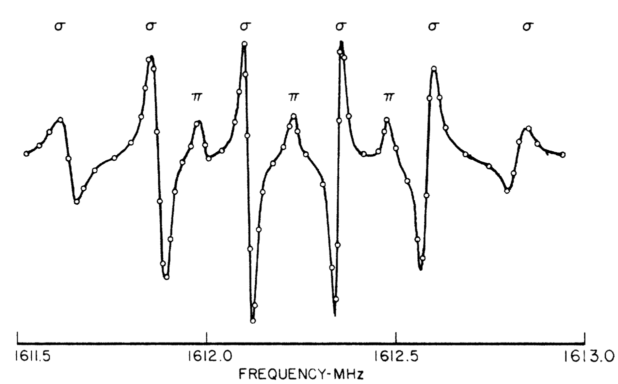

FIG. 1. Point-by-point recording of the 1612-MHz line of OH, split by a static magnetic field of 0.36 gauss. The relative orientations of the microwave electric field, static magnetic field, and magnetic modulation field have been chosen so as to excite both π and σ transitions, although with unequal intensities.

Like the earlier work of Ehrenstein, Townes, and Stevenson,[4] the present measurements were made by the method of microwave absorption in a flowing gas in which OH radicals were generated continuously. Freed from the search problem of the earlier work, however, we have used a highly sensitive superheterodyne cavity spectrometer, rather than a spectrometer of the broad-band transmission-line type. A second and more important improvement has been made in the method of OH production. The chemical-reaction method investigated recently by Kaufmann and Del Greco,[5] in which nitrogen dioxide is mixed with the products of an electric discharge in hydrogen gas, has been found to be a much more abundant source of OH than the earlier method, in which OH is produced by dissociating water vapor in an electric discharge. A detailed description of the experimental method and apparatus will be published later. In brief, the two gases are metered separately into a two-liter quartz flask, located within the spectrometer cavity, and allowed to mix there. The total pressure in the flask is maintained at approximately 2 μ Hg by a mercury diffusion pump. At this pressure the signal-to-noise ratio of the strongest OH absorption is about two thousand to one (with a lock-in detector time constant of 3 sec) and the full linewidths at half-maximum are 15 kHz. Pressure broadening is the dominant source of linewidth, with smaller contributions from saturation, modulation, and field inhomogeneity broadening. With first measurements completed, the spectrometer is now being modified to eliminate these latter sources of linewidth, the aim being to reduce the operating pressure still further, possibly to the extreme required for a molecular-beam mode of operation.

Line-center measurements have been made on π and σ components of each of the four OH transitions. The mean results of 10 or more repeated determinations of each of the zero-field frequencies are

$$F = 2 \rightarrow 1, \quad \nu = 1\,612\,231 \pm 2 \text{ kHz},$$

$$F = 1 \rightarrow 1, \quad \nu = 1\,665\,401 \pm 2 \text{ kHz},$$

$$F = 2 \rightarrow 2, \quad \nu = 1\,667\,358 \pm 2 \text{ kHz},$$

$$F = 1 \rightarrow 2, \quad \nu = 1\,720\,533 \pm 2 \text{ kHz}.$$

The error limits of ±2 kHz (~1 ppm) are approximately four times the standard deviation of the means, and have been chosen purposely large to account for possible systematic errors due to cavity mistuning and magnetic field inhomogeneities. In Table I, these figures are compared with the earlier laboratory measurements and with the astronomical results.

The excellent agreement of the NBS and Cassiopeia-*A* frequencies verifies a not unreasonable assumption that is implicit in the tabulated Cassiopeia-*A* frequencies: to wit, that the OH and H constituents of the same interstellar gas cloud move with the same radial velocity relative to the local standard of rest.

Comparison of the NBS and Sagittarius-*A* frequencies, on the other hand, reveals an unexpected discrepancy. The 1612-MHz interstellar line occurs at a significantly lower frequency relative to the 1665- and 1667-MHz lines than does the corresponding laboratory line. From Table I, the displacement is 30 ± 19 kHz. The 1720-MHz interstellar line, although its frequency is considerably more uncertain, also appears to be displaced in the same direction and by a comparable amount.

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Table I. Comparison of OH frequencies measured in the laboratory and in the interstellar gas. All frequencies are in kHz (kc/sec). Error limits in parentheses apply to the last tabulated figure.

$F \rightarrow F'$	Columbia[a]	NBS[b]	Cassiopeia-*A*[c]	Sagittarius-*A*[d]
2 → 1		1 612 231(2)		1 612 201(17)
1 → 1	1 665 460(100)	1 665 401(2)	1 665 402(7)	
2 → 2	1 667 340(30)	1 667 358(2)	1 667 357(7)	
1 → 2		1 720 533(2)		1 720 515(40)

[a]Reference 4.

[b]Present work.

[c]Reference 1. Tabulated below are rest frequencies derived from the observational results by applying the relative Doppler-shift correction of atomic hydrogen in the same gas cloud.

[d]Reference 3. Tabulated below are rest frequencies relative to those of the preceding column.