VI. RADIO ASTRONOMY

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A. ENVIRONMENTAL SENSING WITH NIMBUS SATELLITE PASSIVE MICROWAVE SPECTROMETERS

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Absorption measurements are being made at 59.0 GHz in our laboratory to substantiate the conclusion we have drawn from an analysis of satellite spectrometer readings[1] that the absorption coefficient of oxygen in air shows stronger dependence on pressure than theoretical prediction. In particular, the brightness temperatures of the Nimbus-5 microwave spectrometer (NEMS) at 58.8 GHz can best be interpreted[2] if the absorption coefficient k varies with pressure p as $k = k_o(p/67\ \text{Torr})^x$, with $k_o = 3.3$ dB/km and $x = 4$, whereas theory predicts $k_o = 1.3$ dB/km and $x = 1.79$ for the Van Vleck-Weisskopf line shape (Method 3), while $k_o = 1.0$ dB/km and $x = 1.51$ for the Gross-Reber line shape (Method 4).

A Fabry-Perot interferometer (FP) used as a microwave spectrometer[3-5] involves the measurement of Q-reduction to determine gaseous absorption. The FP in our experiment is composed of two brass mirrors: a plane mirror, 15" in diameter, and a concave mirror, 11 1/2" in diameter, which has a radius of curvature of ~90". When losses by coupling, conduction, and diffraction are taken into account, such an arrangement in the semiconfocal configuration has an unloaded Q estimated to be 0.5×10^5 at 23 GHz, 2.5×10^5 at 35 GHz, and 3.3×10^5 at 55 GHz. The accurate measurement of a high-Q value is not easy. We use the unconventional method of measuring the phase shift of the envelope of an amplitude-modulated microwave as it passes through the interferometer.[6]

Figure VI-1 is an overall view of the apparatus. The concave mirror hanging down inside a stainless-steel vacuum chamber is supported by three poles of adjustable lengths. The plane mirror, which also acts as the lid of the chamber, has two irises,

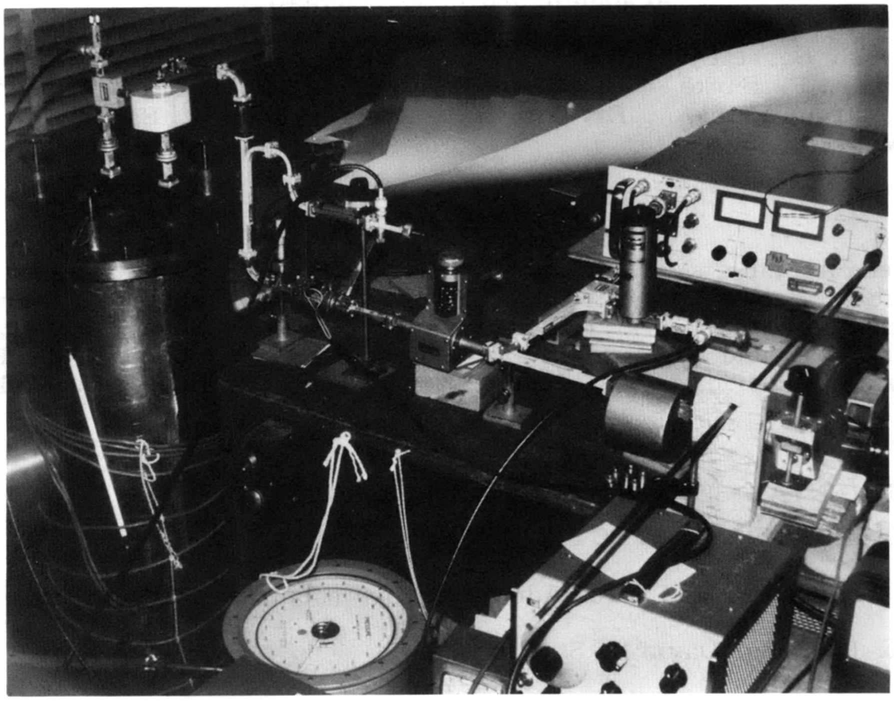

Fig. VI-1. Experimental arrangement (overall view).

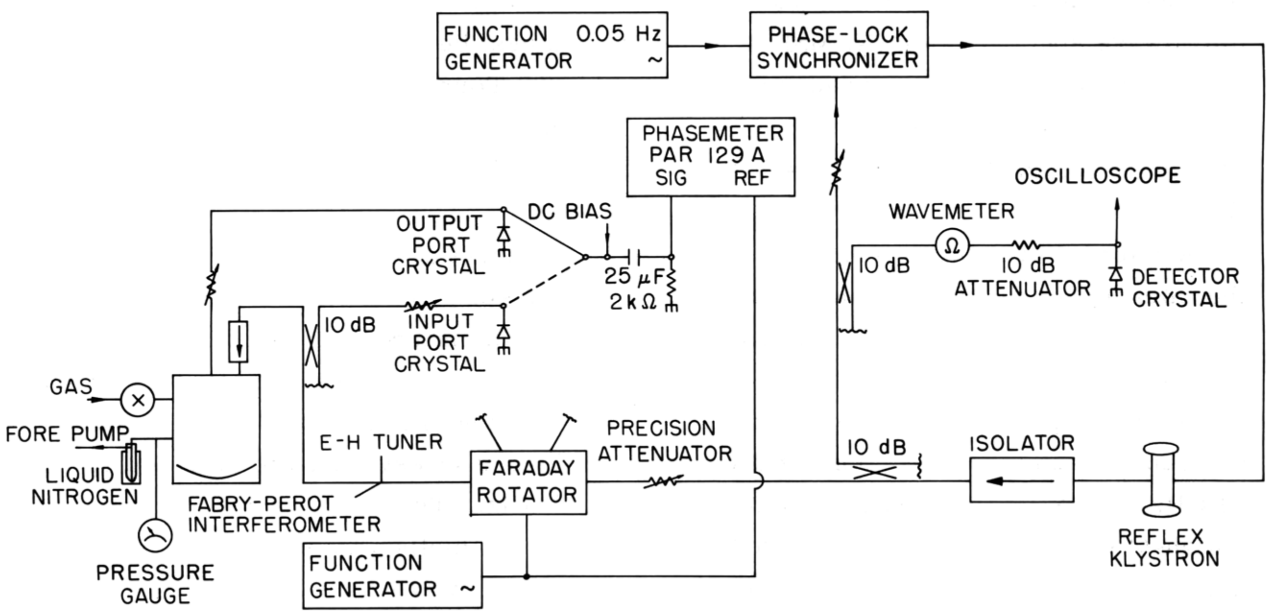

Fig. VI-2. Circuit diagram for measuring the Q of a Fabry-Perot interferometer.

an off-center iris for coupling energy in, and a center iris for coupling energy out. As shown in Fig. VI-2, the microwave is generated by a reflex klystron phase-locked to a reference crystal oscillator, which is electronically swept at 0.05 Hz, so that the microwave is slowly and periodically tuned through several kilohertz about the cavity resonance. Before being coupled into the FP, the microwave is sinusoidally modulated in the 25-100 kHz frequency range by a Faraday rotator. The Q-determination is accomplished by measuring the phase shift of the modulation envelope introduced by the cavity. The phasemeter, which is switched manually between the video crystal detectors at the input and output ports, measures the phase of both signals relative to the sinusoid that is driving the Faraday rotator. The difference in the two phases then gives the desired phase shift at a particular modulation frequency. The procedure is repeated at other modulation frequencies. When the tangent of the phase shift at resonance is plotted against the modulation frequency, a straight line of slope $2Q/f_o$, where f_o is the microwave frequency, should be obtained through the origin. This completes one Q-measurement. A run of data includes the Q-measurement with the cavity evacuated, and at several pressures of absorption gas inside, all at room temperature. Each run is usually preceded by peaking the cavity for maximum transmission of the dominant mode, and ends with a confirmation of the vacuum Q at the start of the run. At each pressure setting, the increase of $1/Q$ over the vacuum value gives $1/Q_{gas}$, which is related to the absorption coefficient k of the gas by $k = 2\pi f_o/cQ_{gas}$, where c is the velocity of light.

For calibration, we measured the intensity of the ammonia inversion spectrum at 36.6 GHz between the two lines with rotational numbers 14 and 15. In 4 runs of data we measured the vacuum Q to be 237.9 K, 238.5 K, 227.0 K and 235.5 K, and ascribed the variation to disturbance caused by mirror tuning that preceded each run. The measurements compare favorably with the 250 K unloaded Q that we have estimated. The 17 data points taken at pressures below 30 Torr can be fitted to a power law in the pressure p (Torr):

$$k_{NH_3}(36.6\ \text{GHz}) = 0.0576\ p^{1.88}\ \text{dB/km}$$

with a standard deviation of 0.46 dB/km (Fig. VI-3). For comparison we show the theoretical pressure profiles when Van Vleck-Weisskopf and Gross-Reber line shapes are assumed. (Intensities of overlapping lines are summed. Details of the calculation are given in Townes and Schawlow.[7]) Our experimental points agree well with both theoretical predictions.

The microwave circuit was then changed to V-band for absorption measurements with dry air. The vacuum Q measured in 4 runs of data gave 136.3 K, 123.2 K, 133 K and 131 K. These average to only half the Q measured at 36.6 GHz, which is inconsistent with the prediction of higher Q values based on calculation. We are investigating

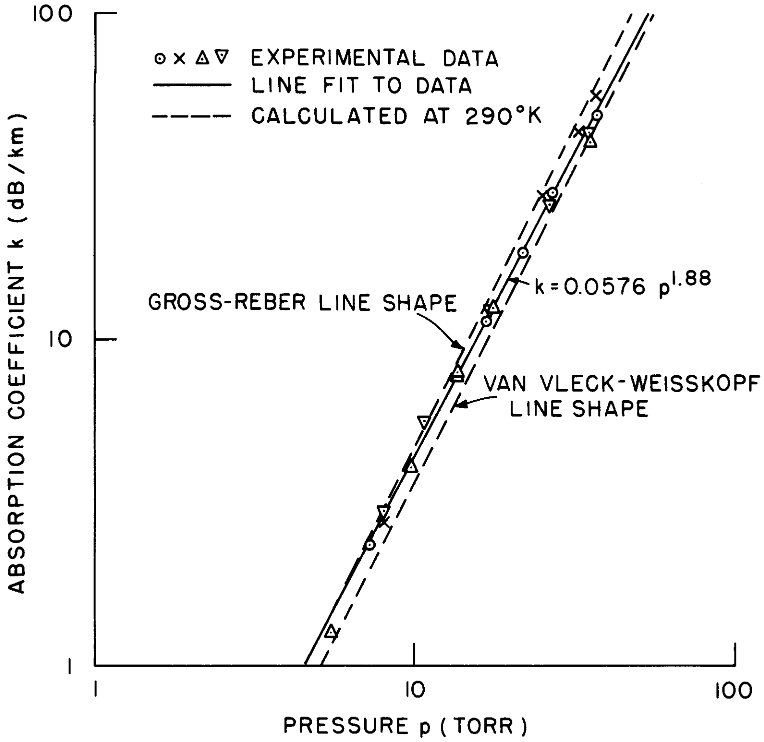

Fig. VI-3.

Ammonia absorption at 36.6 GHz.

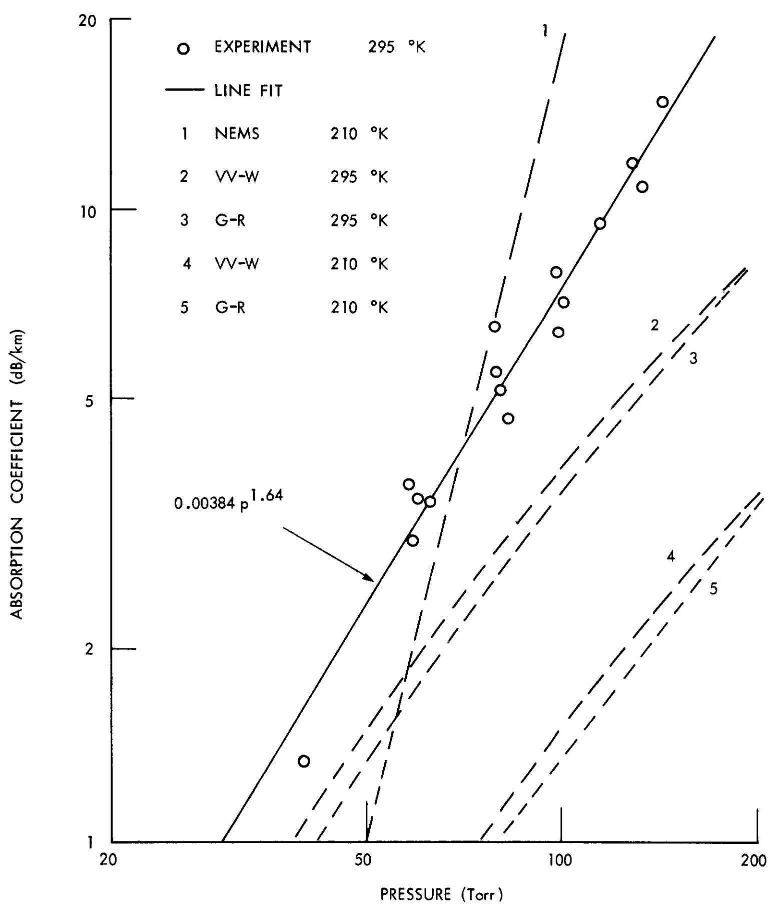

Fig. VI-4.

Air absorption at 59.0 GHz.

a circuit problem that did not arise in the ammonia measurements. Nonetheless, 16 data points were collected at 59.0 GHz (Fig. VI-4). They can be fitted to a power law in the pressure p (Torr).

$$k_{air}(59.0 \text{ GHz}) = 3.77(p/67 \text{ Torr})^{1.64} \text{ dB/km}$$

with a standard deviation of 0.74 dB/km. For comparison, we show the absorption coefficient at 210 K that we inferred from NEMS data, and the absorption coefficient calculated at 210 K and 295 K by summing the intensities of lines that assume either the Van Vleck-Weisskopf or the Gross-Reber line shape. The data obtained thus far confirm tentatively the lower pressure dependence x, although the absolute value of the absorption, k_o, is almost three times that given by theory. In further investigations we shall try to find answers to the anomaly revealed by the satellite data.

References

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