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LABORATORY MEASUREMENTS OF MICROWAVE ABSORPTION FROM GASEOUS ATMOSPHERIC CONSTITUENTS UNDER CONDITIONS FOR THE OUTER PLANETS

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Quite often, the interpretive work on the microwave and millimeter-wave absorption profiles, which are inferred from radio occultation measurements or radio astronomical observations of the outer planets, employs theoretically-derived absorption coefficients to account for contributions to the observed opacity from gaseous constituents. Variations of the actual absorption coefficients from those which are theoretically derived, especially under the environmental conditions characteristic of the outer planets, can result in significant errors in the inferred abundances of the absorbing constituents. The recognition of the need to make laboratory measurements of the absorptivity of gases such as NH_3*,* CH_4*, and* H_2O *in a predominantly* H_2 *atmosphere, under temperature and pressure conditions simulating the outer planets' atmospheres, and at wavelengths corresponding to both radio occultation and radio astronomical observations, has led to the development of a facility capable of making such measurements at Georgia Tech. We describe the laboratory measurement system, the measurement techniques, and the proposed experimental regimen for Winter 1986; with the goal of obtaining feedback from interested investigators on the relative priorities of the various proposed measurements to be made on specific constituents at specific wavelengths.*

INTRODUCTION AND SUMMARY

Radio absorptivity data for planetary atmospheres obtained from spacecraft radio occultation experiments and earth-based radio astronomical observations can be used to infer abundances of microwave absorbing atmospheric constituents in those atmospheres, as long as reliable information regarding the microwave absorbing properties of potential constituents is available. The use of theoretically-derived microwave absorption properties for such atmospheric constituents, or laboratory measurements of such properties under environmental conditions which are significantly different than those of the planetary atmosphere being studied, often lead to significant misinterpretation of available opacity data. Steffes and Eshleman (1981) showed that under environmental conditions corresponding to the middle atmosphere of Venus, the microwave absorption due to atmospheric SO_2 was 50 percent greater than that calculated from Van Vleck-Weiskopff theory. Similarly, the opacity from gaseous H_2SO_4 was found to be a factor of 7 greater than theoretically predicted for conditions of the Venus middle atmosphere (Steffes and Eshleman, 1982). The recognition of the need to make such measurements over a range of temperatures and pressures which correspond to the periapsis altitudes of radio occultation experiments, and over a range of frequencies which correspond to both radio occultation experiments and radio astronomical observations, has led to the development of a facility at Georgia Tech which is capable of making such measurements.

Recently, we have completed shorter wavelength measurements (1 to 3 cm) of the microwave absorptivity of gaseous sulfuric acid under simulated Venus conditions, as well as completing additional vapor pressure studies of H_2SO_4. In September, 1985, we began reconfiguring the planetary atmospheric simulator so as to begin measurements under simulated conditions for the atmospheres of the outer planets (pressures from 1 to 6 atmospheres, temperatures from 150 K to 300 K, and wavelengths from 1 to 22 cm). Since the outer planet atmospheres are predominantly hydrogen and helium, special procedures are being employed for handling and operating in the simulated atmospheres. The microwave absorbing constituents which will be evaluated included ammonia (NH_3) and methane (CH_4), but other constituents may also be tested. In addition to the laboratory work being conducted, application of the absorptivity measurements to observations will be used to develop more accurate profiles for the abundance and structure of microwave absorbing constituents in the atmospheres of the outer planets.

We believe that this effort fulfills a pressing need in the area of planetary radar and radio astronomy. It will provide a better basis for interpretation of existing radio absorptivity data from Voyager 1 and 2 encounters of Jupiter and Saturn, and from expected encounters with Uranus (January 1986) and Neptune (August 1989). It will continue to provide similar bases for interpretation for a wide range of radio astronomical observations of the atmospheres of Jupiter, Saturn, Uranus, and Neptune. (This is especially relevant to a wide range of observations made with the NRAO Very Large Array (VLA) which is currently capable of operations in the 10-0.8 cm wavelength range.) Finally, this program will continue to provide information which will be extremely useful in data analysis and mission planning for new missions such as Galileo.

JUPITER AND SATURN

Jupiter and Saturn have been the subject of both radio occultation and radio astronomical studies. At Jupiter, microwave absorption in the atmosphere has been measured by Voyager radio occultations from about the 0.6 atm pressure level down to the 1.0 atm pressure level at 13 and 3.6 cm wavelengths (Lindal *et al.*, 1981). At Saturn, the same measurements probed down to the 1.4 atm pressure level. Radio astronomical observations in the 1 to 20 cm wavelength range have probed to even lower altitudes (10 atm pressure or greater--see Berge and Gulkis, 1976). In addition, a large number of radio occultation measurements to be made with the Galileo orbiter, plus data collected with the Galileo entry probe (21.4 cm wavelength) will provide an even larger data base of microwave absorptivity data.

For altitudes with pressures less than about 4 atm, gaseous NH_3 has been recognized as the predominant microwave absorber. Below this altitude, liquid clouds begin to contribute to the observable opacity (see Galileo Probe Project Specification, 1980). Since only a single measurement of the microwave absorption properties of NH_3 in an H_2/He atmosphere has been made, (at a single pressure and frequency) we propose to make such measurements in a pressure range from 1 to 6 atmospheres, over a temperature range from 150 K to 300 K, and over a wavelength range from 1 to 22 cm. These measurements would provide an invaluable tool for the interpretation of existing and future radio occultation and radio astronomical data, in addition to greatly reducing current uncertainties as to the NH_3 abundances suggested by such data.

URANUS

Uranus presents one of the most exciting and challenging planetary targets of modern astronomy. Radio astronomical measurements made by Gulkis revealed a microwave spectrum vastly different from those of Jupiter and Saturn. This, and other data, led Gulkis *et al.* (1978) to suggest that the abundance of NH_3 in the Uranus atmosphere may be significantly depleted. In addition, similar studies have suggested a much lower abundance of any microwave absorbing cloud layers than on Jupiter or Saturn (Wallace, 1980).

These results suggest that the upcoming Voyager 2 radio occultation of Uranus may probe to a much deeper level than was probed at Jupiter or Saturn (down to several atmospheres pressure), and that any measured microwave opacity might be that due to methane (CH_4), in addition to, or even to the exclusion of NH_3 (Fox, 1974). With this in mind, we are proposing to measure the absorptivity of CH_4 in an H_2/He atmosphere over a wavelength range from 1 to 22 cm, over a pressure range from 1 to 6 atmospheres, and over a temperature range from 140 K to 200 K. These measurements would provide critically needed data for interpretation of the microwave spectra from radio astronomical observations and for interpretation of absorptivity data from the 1986 Voyager 2 radio occultation experiment.

LABORATORY FACILITY

The experimental approach used to measure the microwave absorptivity and refractivity of gases in a predominantly H_2 atmosphere is similar to that used previously by Steffes and Eshleman (1981 and 1982). As can be seen in Fig. 1, the absorptivity is measured by observing the effects of the introduced gas mixture on Q, or quality factor, of a cavity resonator. The changes in the Q of resonances at numerous frequencies can be monitored by the high resolution spectrum analyzer, since Q is simply the ratio of the frequency of a given resonance to its half-power bandwidth. One resonator provides useful resonances in the 1.3 to 8.5 GHz range, while a smaller unit provides resonances in the 8 to 30 GHz range. The minimum measureable absorptivity, or sensitivity, for this system when operated at 170 K is shown in Fig. 2 as a function of frequency.

One of the major considerations for simulation of the atmospheres of outer planets is refridgeration. Currently, we have available a non-cryogenic refridgerative unit capable of maintaining temperatures down to 140 K. Cryogenic cooling (liquid nitrogen) would be used for lower temperatures.

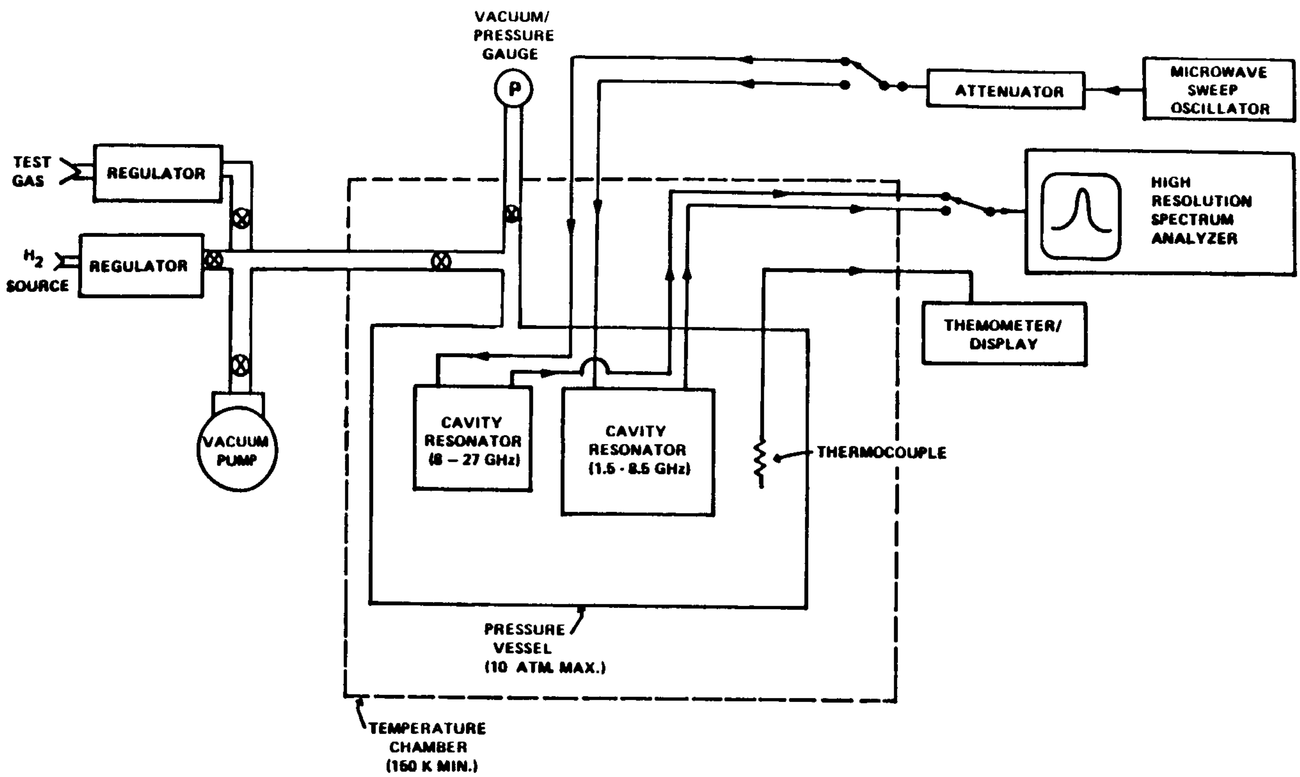

Figure 1. Block diagram of the Georgia Tech Planetary Atmospheres Simulator, as configured for measurements of microwave refraction and absorption of gases under simulated conditions for the outer planets.

Table 1

Minimum Gaseous Abundances Necessary for Measurement by System

Constituent Gas	Abundance of Gas in H_2 atmosphere (total pressure= 6 atm) required for measurement	Partial Pressure of Gas (in atm)	Lowest Possible Temperature for which required abundance can be achieved (K)
NH_3	60 ppm	3.6×10^{-4}	155
H_2-H_2, H_2-He (collisional)	80% H_2 : 20% He	6	20
CH_4	33%	2	120
CO	Not Detectable	---	---

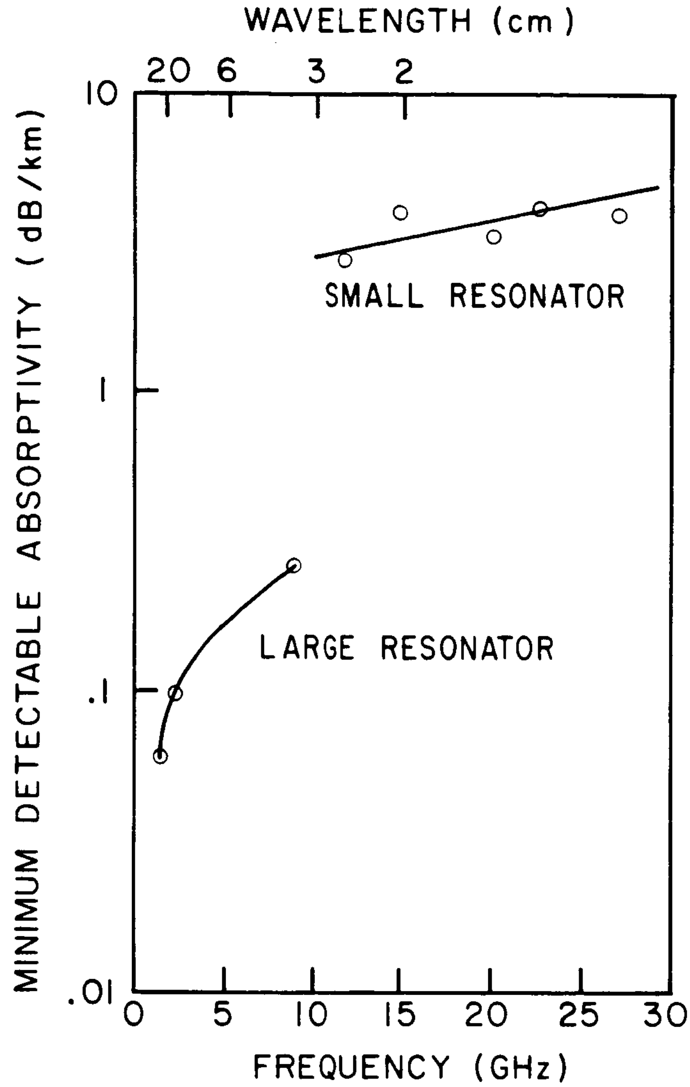

Figure 2. Sensitivity of Planetary Atmospheres Simulator as a function of frequency when operated at 170 K.

Another more critical limitation on how low the temperatures can be taken while still measuring microwave absorption is the saturation vapor pressure of the gas being tested. As shown in Table 1, the lowest temperature for which sufficient quantities of gaseous NH_3 would still exist so that the microwave absorption would be measurable would be ≈155 K. While this would be fine as a Jupiter simulation, it is somewhat above the temperature range for the other planets. It is hoped that the measurements described can be tailored to provide much needed absorptivity data for outer planets constituents which will serve the largest possible number of investigators in the planetary sciences area.

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