III. RADIO ASTRONOMY*

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A. MICROWAVE PROPERTIES OF THE ATMOSPHERE AND SURFACE OF VENUS

Extensive computations have been made of the microwave spectra that would characterize various atmospheric models for the planet Venus. The models considered were the CO_2-N_2 model,[1] the aeolospheric model,[2] and three cloud models. A brief summary of the computations and some of the conclusions are presented here.

In the CO_2-N_2 model the microwave absorption arises from collision-induced dipole moments, which become important at high pressures. Recent measurements by Thaddeus and Ho[3] of the absorption coefficient of CO_2-N_2 mixtures at high pressures and temperatures, and estimates of the CO_2 mixing ratio (Kaplan[4] and Spinrad[5]) have enabled more accurate spectral computations to be made. The CO_2-N_2 model assumed an atmosphere in adiabatic equilibrium composed of 10 per cent CO_2 and 90 per cent

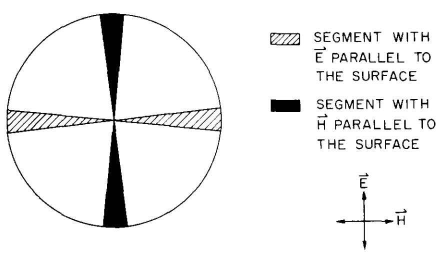

Fig. III-1. Illustrating how the polarization dependence of the surface emissivity can be taken into account.

N_2, with a constant mixing ratio. The temperature was assumed to be 700° K at the surface and to decrease 7° K/km to an isothermal region at 287° K beginning at altitude 60 km. The surface of Venus was assumed to be a smooth dielectric sphere with dielectric constant 5. The computations included the effect of surface reflectivity on the surface emmissivity and on the radiation incident upon the surface. Two brightness temperatures have been computed; one, labeled $\vec{E}//$, is the average brightness temperature for a narrow triangular segment whose surface is everywhere parallel to the electric vector $\vec{E}$, and the other, labeled $\vec{H}//$, is the average brightness temperature

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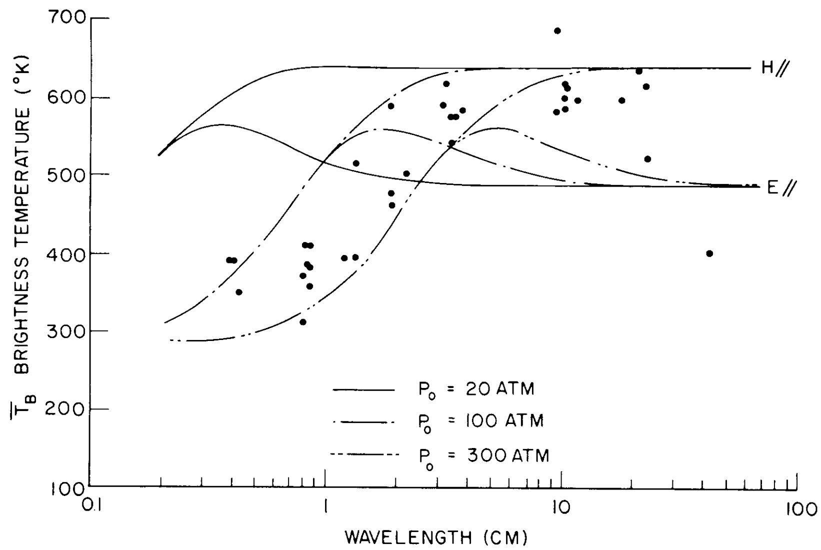

Fig. III-2. Theoretical radio spectra for the CO_2-N_2 model atmosphere.

of a similar segment whose surface is everywhere parallel to the magnetic vector $\vec{H}$ (Fig. III-1).

The results for the first model are shown in Fig. III-2 for surface pressures of 20, 100, and 300 atmospheres. Superimposed upon the figure are dots representing the observations that have been made. The major conclusion for this model is that if the CO_2-N_2 absorption is responsible for the decrease in brightness temperature which occurs at short wavelengths, surface pressures will be in the range 100-300 atmospheres. A second model was considered, which was the same as the first, except that the lapse rate was 4.83° K/km, and there was no isothermal region. The results indicate that even greater surface pressures, 300-1000 atmospheres, are required for this model, and even with these high pressures agreement with the experimental points is poor.

The aeolospheric model presumes an atmosphere containing large amounts of dust. This dust can affect the microwave spectrum both by absorption and scattering. Computations for models containing dust with dielectric constants that were not a function of frequency yielded spectra that varied too slowly to match the observations if only absorption was considered, but varied quite sharply when scattering was included. The equations of radiative transfer were solved for the scattering atmosphere under the assumption of isotropic Rayleigh scattering. The solution was obtained by an iteration procedure on the IBM 7094 digital computer. Results were obtained for several models. The model providing the best agreement with observations assumed dust particle diameters varying linearly from 0.6 mm at the ground to 0 at 90 km. The density also varied

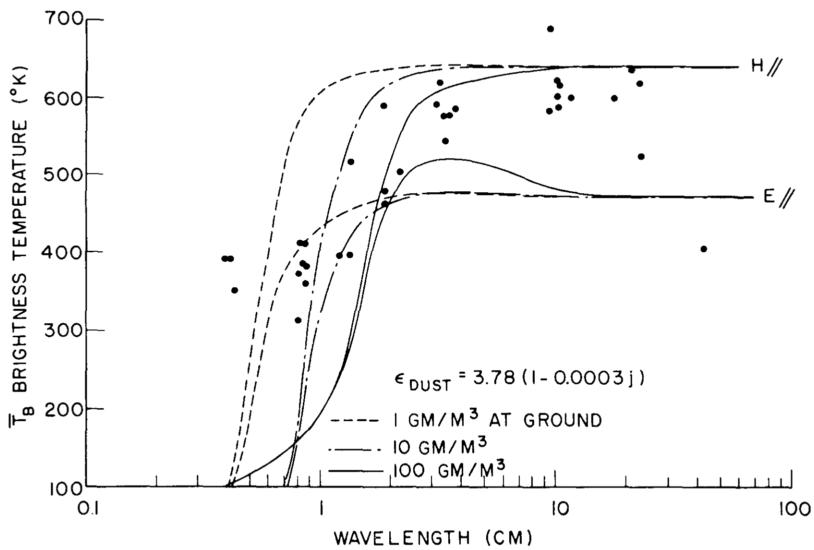

Fig. III-3. Theoretical radio spectra for an atmosphere of dust particles with a maximum size of 0.6 mm. Both absorption and scattering are included in the computation.

linearly, from 10 and 100 g/m^3 at the ground to 0 at 90 km. The temperature distribution and surface model were the same as for the 4.83°K/km CO_2-N_2 model. The result is shown in Fig. III-3. Although the scattering model can explain very rapid decreases in brightness temperature at short wavelengths, it requires large particle diameters, greater than 0.5 mm, and large densities, greater than 10 g/m^3, to be effective. The required densities are reduced if still larger particles are present. It also requires some absorption above the scattering layer to raise the 4-mm temperature to the observed values. Because of the very strong dependence of the scattering cross section Q_s upon the particle diameter D ($Q_s \sim D^6$), the break point in the spectrum would be expected to be strongly dependent upon meteorological conditions in the lower atmosphere.

The cloud models considered were: (i) a cloud with absorption proportional to frequency; (ii) a cloud with absorption proportional to the square of the frequency; and (iii) a water cloud in equilibrium with the water vapor beneath it. The first cloud was of uniform density and composed of particles with a complex dielectric constant of $\epsilon_o = 5(1-0.05j)$, which is typical of many organic substances. This yields an absorption coefficient proportional to frequency. The cloud was 30 km thick with a temperature of 415°K at the bottom, and a temperature of 270°K at the top. The planetary surface was the same as in the previous models. Although this model provided sufficient microwave absorption at short wavelengths and at reasonable cloud densities, 0.1-1 g/m^3, it did not provide a sufficiently abrupt change of brightness temperature in the 0.8-cm to 3-cm region. The second model, which is more characteristic of liquid cloud particles composed of freely rotating dipoles restrained by a simple viscous force, had an absorption coefficient proportional to the square of the frequency. This produced much better agreement with the observations, as shown in Fig. III-4. The 4-mm data can be better matched if the cloud is the same, but at a higher temperature. The data at 10 cm could be better matched if the surface emissivity were somewhat greater. This model has the advantage of simplicity in that it requires only a cloud layer of reasonable densities which absorbs approximately according to the Debye equation for

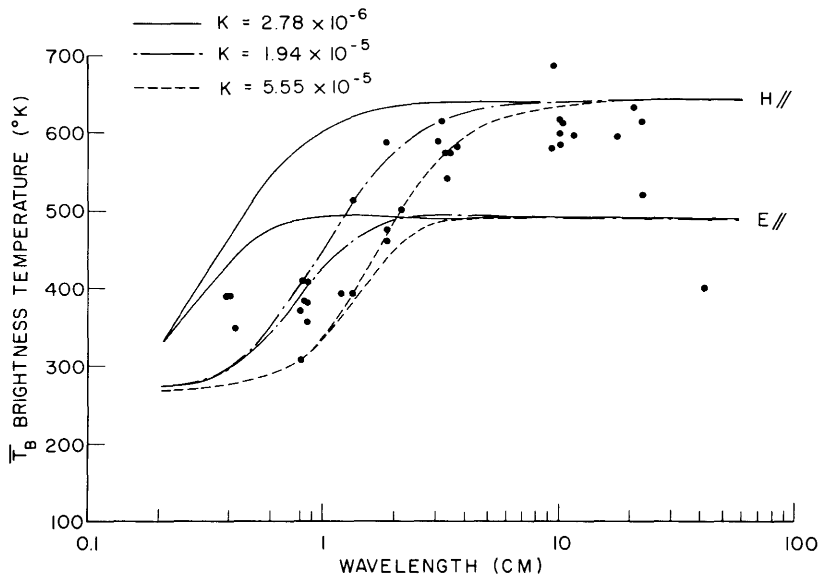

Fig. III-4. Theoretical radio spectra for a cloud model with absorption proportional to the square of the frequency.

nonresonant absorption.

The final model considered was that of a water cloud, 6 km thick, with a temperature of 300° K at the bottom and 270° K at the top. The bottom of the cloud was assumed to be in equilibrium with water vapor that had a constant mixing ratio beneath the clouds. The cloud density was 1 g/m^3, and the atmospheric lapse rate was 4.83° K/km. The results indicate that if the surface pressure is as high as 20 atmospheres, then the atmospheric absorption is too great to be compatible with the 3-cm observations. Lower cloud temperatures, and thus less water vapor beneath the clouds, permit higher surface pressures.

A more complete discussion of the computations and conclusions has been prepared for publication.

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B. K-BAND RADIOMETRY

A five-channel radiometer has been constructed and is operating in the 19-25.5 Gc frequency range. The radiometer is a Dicke-type superheterodyne radiometer with microwave channel-dropping filters and five separate mixers. Digital synchronous detection is used in which the analog signal is converted to pulse frequency so that a synchronously switched up-down counter can detect the signal. The digital output is stored on punched paper tape for processing by the PDP-1 computer. Preliminary tests indicate that the equipment is stable and has $\Delta T_{rms} \approx 0.5\text{-}2°K$ for a time constant of 1 second. Measurements of sky-brightness temperature are now under way. The radiometer will be modified soon to permit measurements in the 21-33 Gc band. In these measurements the 28-ft paraboloid at Lincoln Laboratory, M.I.T., will be used; observations of the sun, moon, various other sources, and extensive observations of the planet Venus will be included. It is hoped that the spectral measurements of Venus in the important region where the transition in brightness temperature occurs will lead to better understanding of the planet's atmosphere.

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