# The Upper Atmosphere of Venus in Light of the Mariner 5 Measurements[1]

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ABSTRACT

Models for the Venus atmosphere and ionosphere are presented and compared with data obtained in the S-band occultation experiment on Mariner 5. Good agreement is found between model and experiment if the Venus atmosphere is composed of essentially pure $CO_2$. An upper limit of about 10% is derived for the $N_2$ mixing rate. It is argued that atomic oxygen is a minor constituent in the upper atmosphere of Venus.

## 1. Introduction

In a recent paper (McElroy, 1968), we presented a model for the atmosphere of Venus above the cloud tops. The model was constructed with a computer code which had previously been employed in studies of the atmospheres of Mars and Mercury (McElroy, 1967; Belton *et al.*, 1967). The model for Venus was based on a pressure-temperature reference point suggested by ground-based spectroscopic studies (Belton *et al.*, 1968; Belton, 1968). The height scale was defined relative to that point. In this paper we shall place the height scale on an absolute basis using the results obtained by Kliore *et al.* (1967) in the Mariner 5 occultation experiment. We shall compare our neutral structure model with the Mariner 5 results. As we shall see, our model is in good agreement with the radio occultation data.

We shall also include a brief discussion of results obtained by de Vaucouleurs and Menzel (1960) from observations of the visual occultation of Regulus by Venus in 1959. The densities which they infer are in good agreement with our model. They also report information on the atmospheric scale height, and scale height gradient. These results are more difficult to understand and we shall argue that the scale-height information is suspect.

From the S-band occultation experiment, Kliore *et al.* were able to deduce important data on the structure of the dayside Venus ionosphere. The ionospheric measurements allow one to place important constraints on the acceptable theoretical models for the Venus atmosphere. We shall demonstrate that the simplest possible model, based on an assumed composition of pure $CO_2$ at all levels, is in excellent agreement with both the neutral atmosphere and the ionosphere observed by Kliore *et al.* On the basis of our ionospheric studies we conclude 1) that molecular nitrogen can be present in at most trace amounts, and 2) that there can be little dissociation of $CO_2$ even in the upper atmosphere.

## 2. The neutral atmosphere

Our model for the neutral atmosphere is presented in Fig. 1. Using the Mariner occultation data, we located the spectroscopic point at a radial distance of 6110 km from the center of Venus. This model is the same as one published earlier (McElroy, 1968). It is based on an assumed composition of pure $CO_2$ at all heights. We employed extreme ultraviolet (EUV) solar fluxes scaled by a factor of 1.5 from data obtained by Hinteregger *et al.* (1965) near sunspot maximum. We believe that the model shown here should be appropriate for the conditions of solar activity which pertained at the time of the Mariner 5 and Venera 4 encounters. For comparison, we have included in Fig. 1 the Mariner 5 results.

Evidently our model provides good agreement with the occultation data. One feature of the model deserves particular comment. Above 6110 km the temperature lapses slowly with increasing altitude; the mean gradient between 6110 and 6160 km is about 2K $km^{-1}$. Many scientists, however, have interpreted the preliminary announcements of Mariner 5 results in terms of an isothermal region above the clouds. There is no positive evidence to support this position. On physical grounds we expect a small lapse rate. Furthermore, temperatures obtained by direct inversion of the occultation data (Kliore *et al.*, 1967) appear to indicate the presence of a lapse rate comparable to that shown by our model.

The number densities reported by de Vaucouleurs and Menzel (1960) are also in good agreement with our model. They find a particle density of about $6\times10^{13}$

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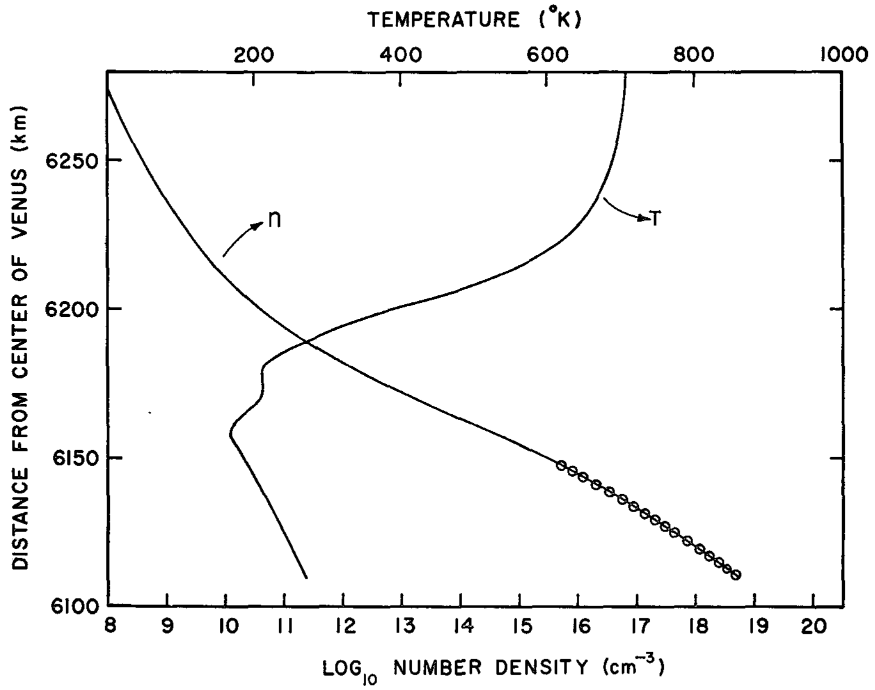


FIG. 1. A model for the neutral atmosphere of Venus. A composition of pure $CO_2$ is assumed. The Mariner 5 occultation data are indicated by circles.

$cm^{-3}$ at a radial distance[3] of 6169±2 km. They also report values for the atmospheric scale height and for the scale height gradient. For an assumed composition of pure $CO_2$, their scale height indicates a temperature of about 300K, significantly larger than the temperature of 200K which is indicated by the model. However, it should be emphasized that any direct information on the scale height requires numerical differentiation of observational data. Information on the scale height gradient requires a second differentiation of these data. From a cursory examination of the raw data, we believe that the scale height cannot be determined to better than about a factor of 2. The temperature information obtained from the Regulus experiment is therefore of little interest. The density or pressure data are very valuable, however. A measure of density, even within a factor of 2 or 3, at a well-defined level provides a very important check on any model. We believe that the Regulus data do indeed provide such a check.

We have investigated a variety of alternative models for Venus. In these models we allowed for the possible presence of molecular nitrogen. From detailed comparison of models with observations of the neutral atmosphere we inferred an upper limit of 25% for the acceptable $N_2$ mixing ratio. As we shall see in the next section, however, a more stringent upper limit can be derived from the ionospheric results.

[3] This value differs slightly from the radial distance given in the original publication. The new value reflects a small change in the best estimate of the astronomical unit.

## 3. The ionosphere

A simple model for the Venus ionosphere is presented in Fig. 2 which also includes the electron density profile measured by Kliore *et al.* (1967). The model is based on the neutral density profile displayed in Fig. 1. We used photo-absorption cross sections tabulated by Henry and McElroy (1968) and assumed that electrons are produced and removed by the reactions

$$h\nu + CO_2 \rightarrow CO_2^+ + e, \quad (1)$$

$$CO_2^+ + e \rightarrow CO + O. \quad (2)$$

For the recombination coefficient we adopted the value $3.8\times10^{-7}$ $cm^3$ $sec^{-1}$ measured by Weller and Biondi (1967).

The agreement between model and observation is evidently very good. Calculated and observed electron densities differ by less than 30% at most altitudes. The suggestion of a secondary peak in the observed profile is also reproduced by the model. Both the main and subsidiary peaks in the model are displaced from the observed peaks in the same direction, by about the same amount. The main peak is formed by EUV radiation, the secondary peak by soft x-rays. They can therefore be identified as F1 and E layers, respectively, by analogy with their terrestrial counterparts.

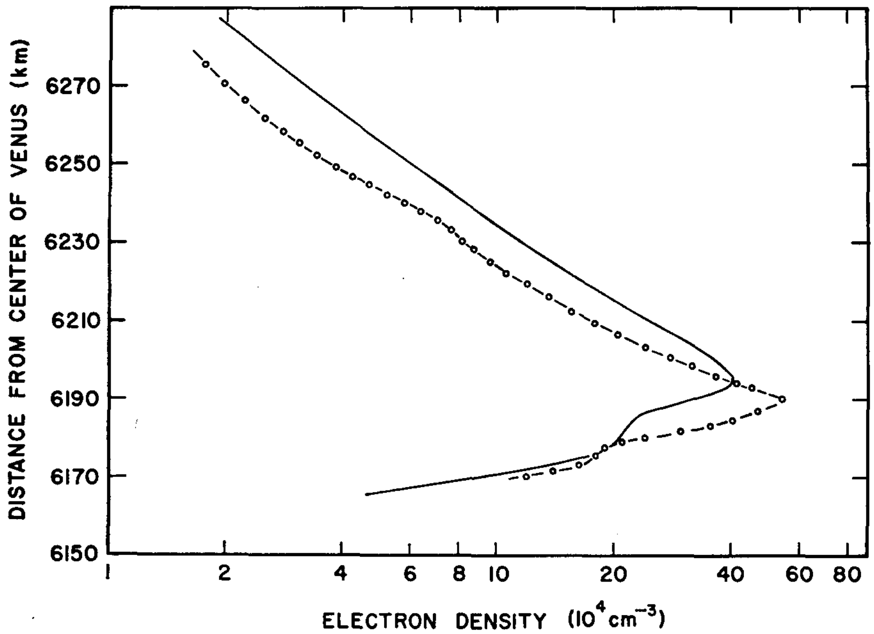


FIG. 2. A model for the Venus ionosphere. The model was constructed using the data shown in Fig. 1. As in that figure, the Mariner data are indicated by circles.

The agreement between the slopes of the observed and calculated electron density profiles is very good and implies important support for our neutral model. In particular, it suggests that the calculated value of 708K for the exospheric temperature should be quite accurate. A recent analysis of the ultraviolet photometer experiment of Mariner 5 (Barth *et al.*, 1968) gave an exospheric temperature of 650±50K and appears also to support our model. However, the same analysis concluded that the upper atmosphere of Venus contained large amounts of molecular hydrogen. Molecular hydrogen was invoked by the experimenters in order to explain some puzzling features of their data. Because of these features and the arbitrary nature of the $H_2$ hypothesis, we are reluctant to place any weight on the value inferred for the exospheric temperature. At this time, the ionospheric measurements provide the best support for the upper atmospheric model developed in this paper.

We investigated alternative models for the Venus ionosphere and found that best agreement between theory and observation requires an atmosphere composed of essentially pure $CO_2$ at all levels. If the turbopause occurs at about the same density level as on earth, then the upper limit to the acceptable amount of $N_2$ is about 10%. By the same token, the fractional abundance of atomic oxygen at the turbopause must be less than about 5%. If the turbopause occurs at a higher altitude these limits must be increased; if it occurs lower they will be decreased, and the ionosphere in this case would impose very important restrictions on any photochemical model for the Venus upper atmosphere.

## 4. Summary

We presented a model for Venus based on an assumed composition of pure $CO_2$. Calculated neutral densities were found to be in good agreement with Mariner 5 and Regulus occultation results. We developed models for the Venus daytime ionosphere, a pure $CO_2$ model giving excellent agreement with Mariner 5. The ionospheric data suggested an upper limit of 10% for the acceptable mixing ratio of $N_2$ in the Venus atmosphere. The ionospheric analysis indicated also that atomic oxygen is a minor constituent, at least below about 6270 km. This latter conclusion illustrates the unusual nature of $CO_2$ photochemistry on Venus.

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