MODELS OF THE VENUS IONOSPHERE

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Theoretical modeling of the daytime Venus ionosphere can be used to augment the measurements of Mariner V made during the 1967 fly-by mission of Venus. The models discussed here are obtained by solving the equations of heat conduction for the electron, ion, and neutral gases along with the momentum and chemical equations for the charged particle densities [1, 2, 3]. When the model is brought into conformity with as much of the data as is possible, constraints can be placed on some of the unknown parameters such as the electron and ion temperatures, and the strength of the magnetic field in the topside Venus ionosphere.

Most of the boundary conditions needed to construct the ionosphere models can be obtained directly from the Mariner V measurements [4]. The upper boundary is selected to be at the altitude of the observed abrupt termination of the electron density profile near 500 km. Since the peak electron density of 5.2×10^5 cm^{-3} occurs at an altitude of 135 to 140 km, the lower boundary, or reference altitude, is placed at 100 km. It has been suggested by several authors that the abrupt termination of the electron density profile in the topside ionosphere, the ionopause, arises from the fact that the magnetic fields carried along by the solar wind are forced to pile up on top of the highly conducting ionosphere. This magnetic obstacle then forms a natural upper boundary for the ionosphere and interacts with the super-alfvenic solar wind to form a bow shock that has been observed at about 50 000 km from Venus.

If the momentum and energy equations are applied across the bow shock, the resulting density just within the bow shock is about 12 cm^{-3} with a corresponding proton temperature of approximately 4×10^6 K. Near the ionopause these values can be used to obtain a pressure balance that requires a magnetic field build up to about 50 γ. Since the ionopause is interpreted as the interface between the solar wind and the Venus ionosphere, a balance must be made between the total solar wind pressure P_w and the total charged particle pressure P_c immediately below the ionopause. This pressure balance, $P_c = P_w \cong KNMV^2 \cos^2\psi$, calculated at $\psi = 45°$ from the subsolar wind point, forms one of the boundary conditions for our model. The precise value of the pressure depends upon the value of the accomodation coefficient K [5]. Since the most likely value lies near one, we have adopted $K=1$ to obtain $P_c = 8.78 \times 10^{-9}$ dyne-cm^{-2} for a solar wind velocity $V = 590$ km/sec and a density of $N = 3$ cm^{-3}. Figure 1 illustrates this schematically.

The presence or absence of a magnetic field has important consequences for the thermal structure of the charged particles. There are two extremes: (1) where the presence of an essentially horizontal magnetic field inhibits thermal conduction across field lines and (2) where due to the complete absence of a magnetic field or to the presence of a tilted magnetic field and possible turbulence, the thermal structure is

Sagan et al. (eds.), Planetary Atmospheres, 23–27.
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https://doi.org/10.1017/S0074180900102542 Published online by Cambridge University Press

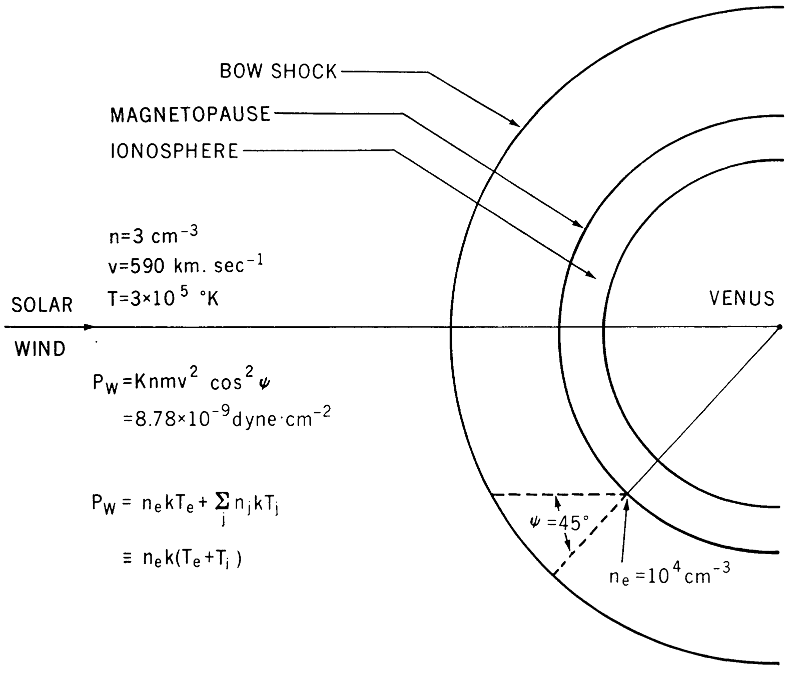

Fig. 1. Schematic representation of the solar wind interaction with the Venus ionosphere.

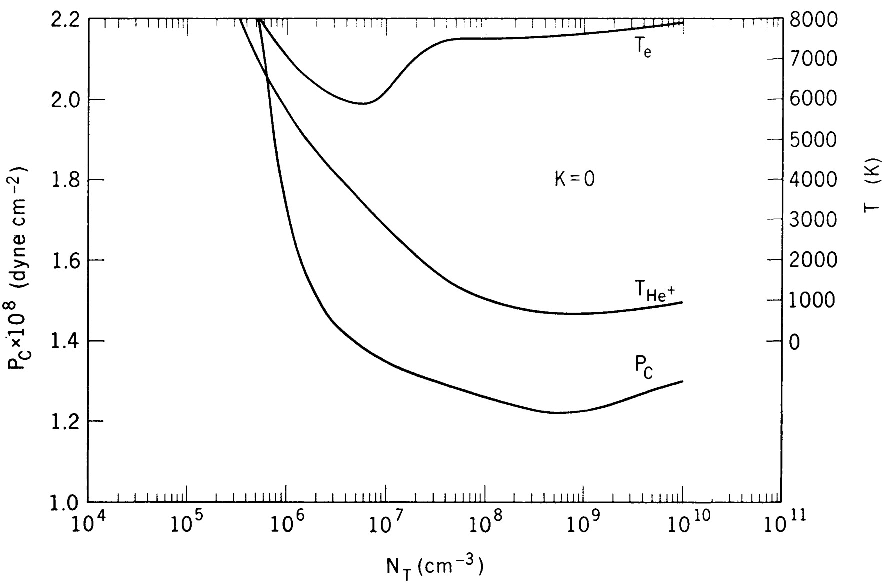

Fig. 2. The charged particle pressure P_c, electron temperature T_e, and major ion temperature T_{He^+} just below the ionopause as a function of the neutral helium concentration N_T at the reference altitude 100 km. The thermal conductivity $K=0$.

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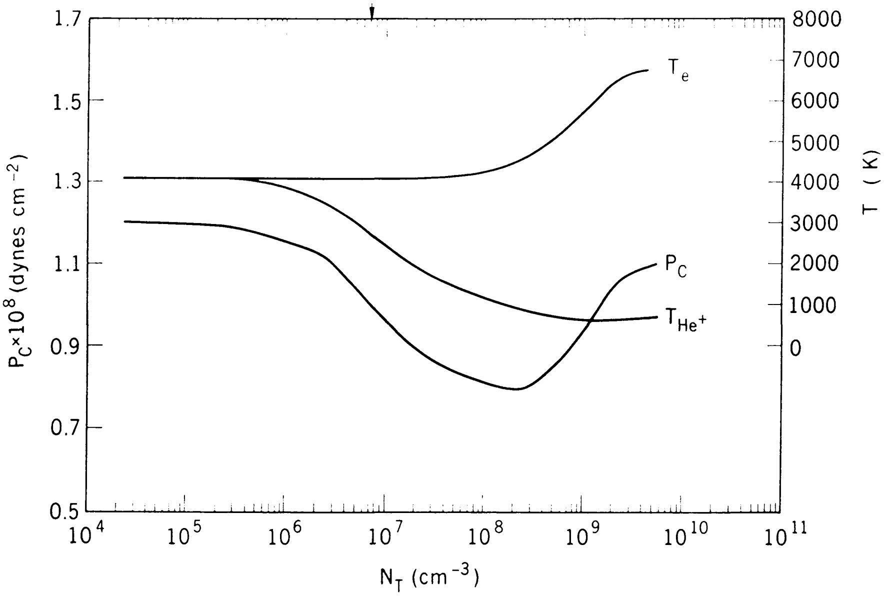

Fig. 3. The same conditions as in Figure 2, except $K = 0.006\ K_{\parallel}$.

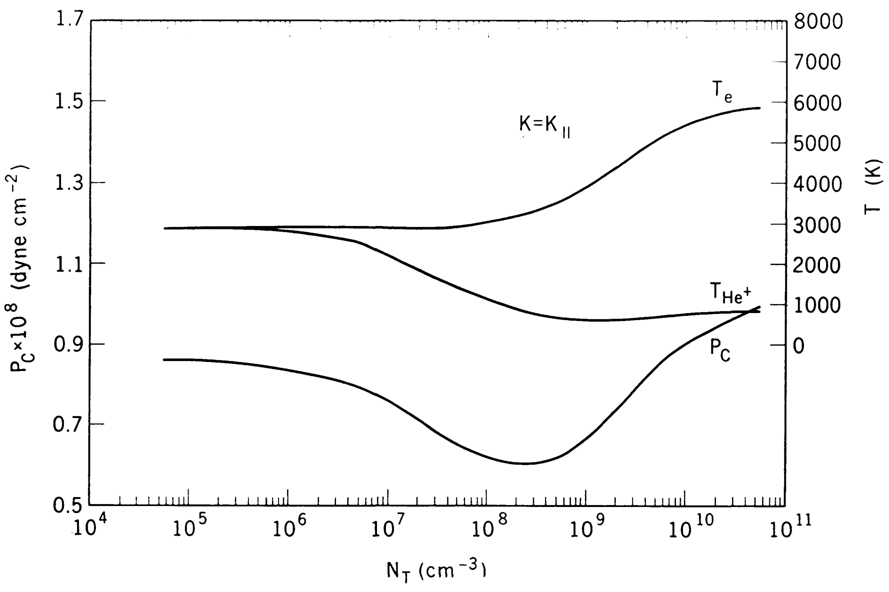

Fig. 4. The same conditions as in Figure 2, except $K = K_{\parallel}$.

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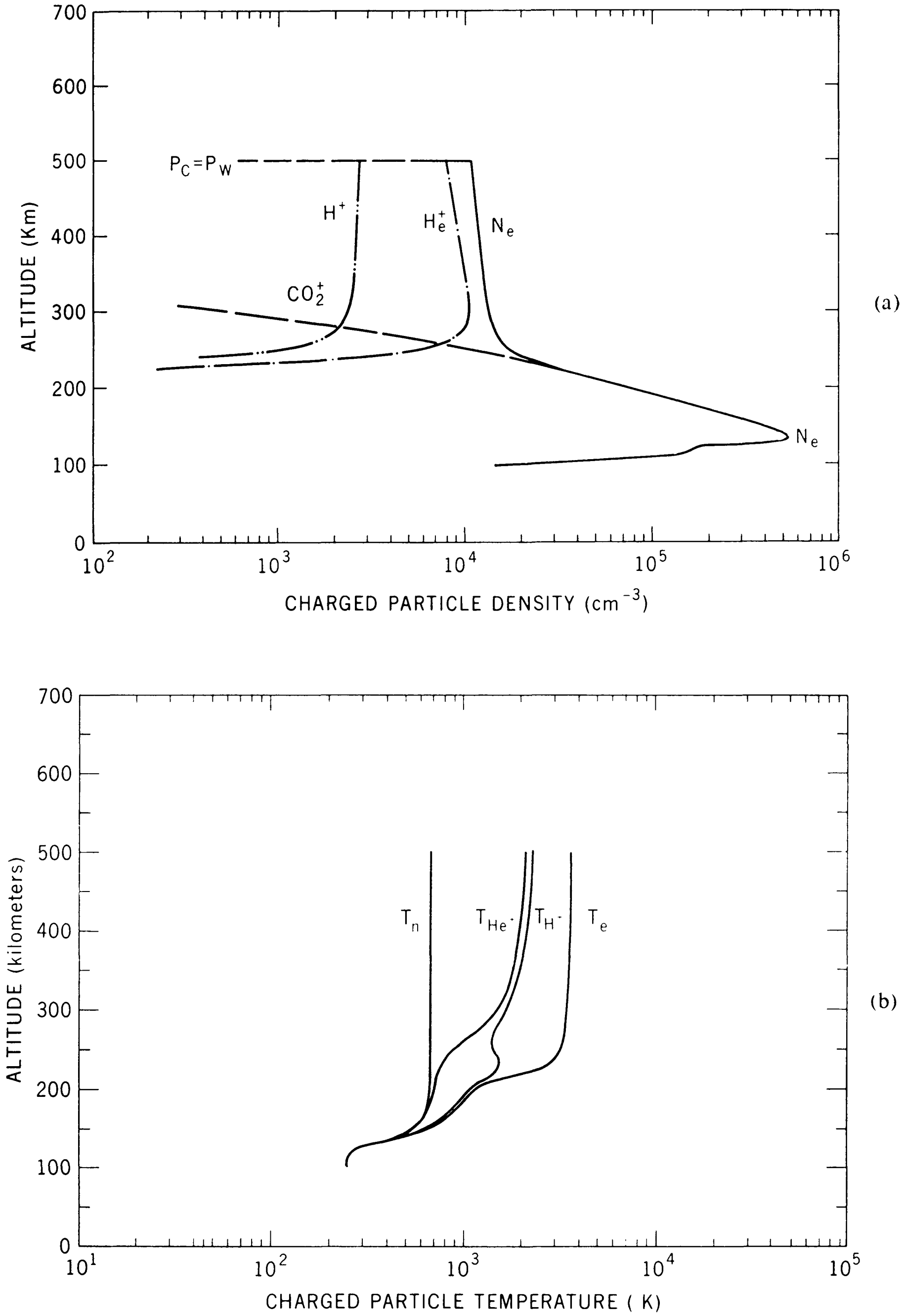

Fig. 5a, b. The electron, ion, and neutral gas temperatures, and the ion composition for boundary conditions compatible with the required pressure balance, $P_c = P_w \simeq KNMV^2 \cos^2 \psi$, and when $K = 0.006\ K_\parallel$. At 100 km $(N_2) = 5 \times 10^8$, $(CO_2) = 2 \times 10^{13}$, $(H_2) = 4 \times 10^6$, $(He) = 5 \times 10^7$, $(H) = 2 \times 10^4$, $(D) = 1 \times 10^6$, with a hydrostatic distribution above 100 km.

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strongly controlled by thermal conduction. If a series of solutions are constructed as shown in Figures 2, 3, and 4, the density of neutral helium N_T at 100 km, the strength of the magnetic field within the ionosphere, and the effective tilt* (in terms of magnetic dip angle) can be estimated. Since a magnetic field within the ionosphere exerts a pressure $B^2/8\pi$, the charged particle pressure need only make up the difference to balance the solar wind pressure. For example, for fields of 10, 20, and 30 γ, P_c (500 km) must be 8.4×10^{-9}, 7.2×10^{-9}, and 5.2×10^{-9} dyne-cm^{-2} respectively. As can be seen from the figures, no solutions exist for dip angles less than about 3.5°, which is equivalent to the thermal conductivity K less than 0.0037 $K_{\|}$. Because of the essentially horizontal nature of the induced magnetic field and the small upper limit placed on a possible intrinsic planetary magnetic moment [6], large effective dip angles are not possible. Thus, the magnetic field within the ionosphere has a strength between 10 and 20 γ with an effective magnetic dip angle near 4.5° ($K = 0.006\, K_{\|}$). For these values, the neutral helium density at 100 km must lie in the range 3×10^7 to 6×10^8 cm^{-3} as can be seen from Figure 3.

Selecting boundary values corresponding to the acceptable range of solutions in Figure 3, the thermal structure and ion composition of the daytime Venus ionosphere can be obtained. The solutions shown in Figure 5 predict that the electron temperature T_e and the major ion temperature T_{He^+} are not in thermal equilibrium with the neutral gas temperature T_n except at altitudes near 100 km. In the region near 500 km, $T_e = 3700$ K, $T_{He^+} = 2100$ K, and $T_n = 660$ K.

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* The effective magnetic dip angle may be composed in part of: (1) an actual geometrical tilt derived from the sum of the intrinsic and induced fields; (2) bulk motion of the high β Venus ionosphere that produces significant distortion in the magnetic field; (3) the possible presence of turbulence that can change the effective thermal conductivity $K = \Omega K_{\|}$.

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