

This work was written as part of one of the author's official duties as an Employee of the United States Government and is therefore a work of the United States Government. In accordance with 17 U.S.C. 105, no copyright protection is available for such works under U.S. Law.

Public Domain Mark 1.0

<https://creativecommons.org/publicdomain/mark/1.0/>

Access to this work was provided by the University of Maryland, Baltimore County (UMBC) ScholarWorks@UMBC digital repository on the Maryland Shared Open Access (MD-SOAR) platform.

Please provide feedback

Please support the ScholarWorks@UMBC repository by emailing scholarworks-group@umbc.edu and telling us what having access to this work means to you and why it's important to you. Thank you.

generated in the first N-N collision, also could possibly explain the effect. A simple model shows that such a particle could produce a detectable shower with the measured delay observed in events A and B if the particle mass is $\sim 10 \text{ GeV } c^{-2}$ and its energy $E_0 \sim 10^{12} \text{ eV}$. Further work is under way at the same altitude (3,500 m).

It seems to us that the structure in the Čerenkov pulses which we have obtained with the fast technique opens a new approach to the study of air showers.

G. BOSIA
C. CASTAGNOLI
M. DARDO
G. MARANGONI

Laboratorio di Cosmo-geofisica del
Consiglio Nazionale delle Ricerche,
Istituto di Fisica Generale dell'Università,
10125 Torino.

Received November 18, 1969.

¹ Galbraith, W., and Jelley, J. V., *Nature*, **171**, 349 (1953).

² Blackett, P. M. S., *Phys. Soc. London Gassiot Committee Report*, 34 (1948).

³ Jelley, J. V., *Prog. Elementary Particle and Cosmic Ray Phys.*, **9**, 41 (1967).

Topside Ionosphere of Venus and its Interaction with the Solar Wind

THE abrupt termination of the daytime ionosphere of Venus at about 500 km observed with the Mariner V two-frequency occultation experiment provides an extremely interesting picture of the direct interaction of the solar wind with a planetary ionosphere^{1,2}. It has been suggested that a pseudo-magnetopause is formed by magnetic fields carried along by the solar wind and forced to pile up on the topside of the highly conducting planetary ionosphere^{3,4}. This magnetic obstacle then interacts with the super-alfvénic and supersonic solar wind to form a bow shock; evidence for such a bow shock has been obtained by experiments on Mariner V and Venera IV (refs. 2 and 5).

We have used the observed properties of the solar wind² to determine order of magnitude estimates of the characteristic parameters in this interaction.

A pressure balance at the stagnation point formed with the streaming pressure of the solar wind leads to a magnetic field build-up of approximately 50γ . A balance between the streaming pressure of the solar wind $P_w = K n m v^2 \cos^2 \Psi$ and the plasma pressure $P_c = Nk(T_e + T_i)$ in the topside ionosphere of Venus is consistent with the sharp cut-off in the electron density profile. At $\Psi = 45^\circ$ from the sub-solar point where the electron density of the topside ionosphere was observed to be $N \approx 10^4 \text{ cm}^{-3}$ at the 500 km cut-off ("ionopause")¹, we calculate the streaming pressure of the solar wind to be about $8.8 \times 10^{-9} \text{ dynes cm}^{-2}$ using an accommodation coefficient $K=1$ as is frequently done for the Earth's magnetosphere⁶. With this solar wind pressure and the observed electron density of the topside ionosphere, we obtain about 6,000 K for the plasma temperature ($T_e + T_i$) of the topside ionosphere. In the following we shall discuss the important constraints which the solar wind interaction places on a self-consistent model of ionospheric temperatures and densities.

The presence or absence of a magnetic field within the ionosphere has important consequences for the structure of the Venus ionosphere. There are two extreme cases: (1) where the presence of an essentially horizontal magnetic field inhibits thermal conduction across field lines, and (2) where

either because of the complete absence of a magnetic field or the presence of a tilted magnetic field the thermal structure is controlled by parallel heat conduction. An induced magnetic field due to the interaction of the solar wind with the conducting ionosphere or the presence of a small intrinsic planetary magnetic field can lead to a non-horizontal field within the Venus ionosphere. The upper limit for such a magnetic field inside the ionosphere is estimated to be about 40γ (J. L. Blank and W. R. Sill at the IAGA Symposium, Madrid, 1969). The following discussion assumes the more likely case of a non-horizontal magnetic field within the Venus ionosphere using a thermal conduction coefficient of $0.25 K_{II}$. It is not our intention to discuss the detailed ionic composition, so we selected a relatively simple photochemical model for the lower regions of the ionosphere based on the work of McElroy⁷. We have taken CO_2 to be the dominant heavy neutral species at 100 km, and H and He are taken to be the important light neutral constituents. We also have investigated the effect of the presence of H_2 or deuterium (D), but their presence does not affect our results significantly. As a result of using hydrostatic equilibrium for the distribution of the neutral gas density, H and He become the dominant species at higher altitudes. It therefore follows that the ionization peak at about 130 km will be controlled by the neutral CO_2 , while the charged particle pressure in the topside is strongly influenced by H and He. For the light ions H^+ and He^+ we have solved the usual balance equations of hydrostatic pressure including gravitational and electrical forces. Combining these with the equations arising from the thermal balance in a multicomponent plasma (including the neutral gases) a self-consistent solution for the temperatures and densities has been obtained⁸.

We have selected several boundary conditions based, wherever possible, on published values. At the lower boundary of 100 km we used a neutral temperature of $T_n = 250^\circ$ and a CO_2 density of $2 \times 10^{13} \text{ cm}^{-3}$ comprising at least 99 per cent of the total density. The remaining 1 per cent or less was adjusted so that the corresponding topside plasma pressure balances that of the solar wind and simultaneously approximates the observed scale height of electron density. Because the light ion composition is experimentally unknown, we have assumed H^+ (or D^+) and He^+ to be the main constituents of the topside ionosphere. The electron density $N = [\text{He}^+] + [\text{H}^+] + [\text{CO}_2^+]$ was selected to match the observed electron density at 500 km.

Fig. 1 shows the computed ionospheric model with He^+ as the dominant ion. The electron temperature has the value of $T_e = 4,090 \text{ K}$, as compared with the ion temperatures which have a value of $T_i \approx 1,900 \text{ K}$, considerably higher than the neutral gas temperature $T_n = 550 \text{ K}$. The

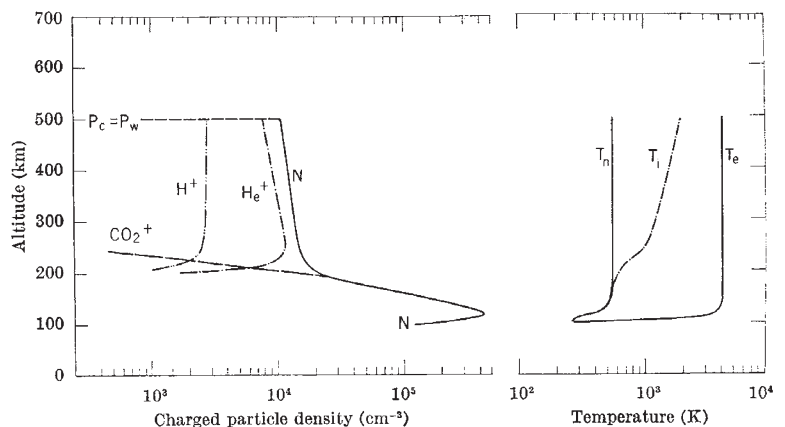


Fig. 1. Charged particle densities and temperatures for the Venus ionosphere when the electron thermal conductivity is $0.25 K_{II}$. The dashed line $P_c = P_w$ represents the cut-off in electron density ("ionopause") arising from the pressure balance between the solar wind and the charged particles of the Venus ionosphere. The actual ionopause is expected to be a layer whose thickness should be of the order of a proton gyroradius, instead of the abrupt cut-off shown.

peak of electron density and the scale height of topside electron density for this model are in good agreement with the Mariner occultation data.

A similar ionospheric model satisfying the observed conditions is one where H^+ (or D^+) is the dominant ion in the topside ionosphere. Although such a model also gives reasonable agreement with the observed values, we argue that the high value required for the H^+ density (and/or D^+ density) in the topside ionosphere seems unlikely, because the observed density of neutral hydrogen is thought to be relatively low⁹ and, in contrast to the Earth, H^+ is produced by photoionization rather than by charge exchange. We therefore favour the model in which He^+ is the dominant topside ion with relatively hot electrons compared with the ion and neutral gases.

In the other limiting case of a horizontal rather than a slightly inclined magnetic field, the thermal structure of the topside ionosphere is significantly different because heat conduction does not play a significant part due to the inhibiting effects of this horizontal magnetic field. In this case, the electron temperature is higher and the ion temperature is lower than in the model presented in Fig. 1.

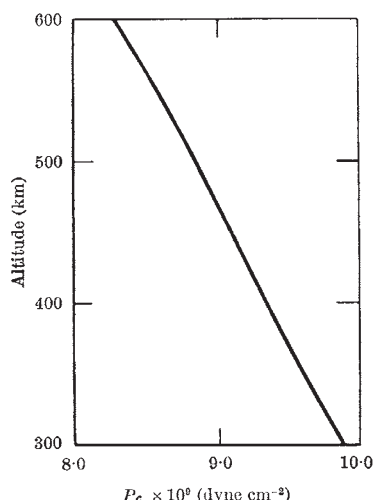


Fig. 2. Charged particle pressure $P_c = Nk(T_e + T_i)$ in the topside Venus ionosphere. At the altitude of the ionopause (500 km), $P_c = 8.8 \times 10^{-9}$ dyne cm^{-2} .

Fig. 2 shows the total pressure distribution based on the density and temperature distributions of Fig. 1. The pressure curve extended to 600 km was obtained by solving the density and temperature equations simultaneously with pressure balance between solar wind and ionospheric plasma pressure at 500 km. The very slow pressure decrease with altitude suggests that the altitude at which the ionosphere terminates (ionopause or anemopause²) is a strong function of solar wind pressure. If the solar wind pressure changes by a small amount, our model predicts a substantially unchanged ionosphere with an ionopause at a different altitude. It also suggests that the ionospheric boundary is flat-nosed at the sub-solar wind point and somewhat bulged out near the terminator due to the effect of the aspect angle in the pressure balance equation. Because the streaming pressure of the solar wind on the night side of Venus is negligible, the ionosphere would there extend to considerable altitudes as reported by Mariner V (ref. 1).

S. J. BAUER
R. E. HARTLE
J. R. HERMAN

Laboratory for Planetary Atmospheres,
NASA, Goddard Space Flight Center,
Greenbelt, Maryland.

Received October 24; revised November 17, 1969.

¹ Mariner Stanford Group, *Science*, **158**, 1678 (1967).

² Bridge, H. S., Lazarus, A. J., Snyder, C. W., Smith, E. J., Davis, L., Coleman, P. J., and Jones, D. E., *Science*, **158**, 1669 (1967).

³ Dessler, A. J., in *Atmospheres of Mars and Venus* (edit. by Brandt, J. C., and McElroy, M. B.), 241 (Gordon and Breach, 1968).

⁴ Johnson, F. S., *J. Atmos. Sci.*, **25**, 658 (1968).

⁵ Dolginov, S. S., Yeroshenko, E. G., and Zhuzgov, L. N., *Kosmich. Issled.*, **6**, 561 (1968).

⁶ Spreiter, J. R., and Alksne, A. Y., *Revs. Geophys.*, **7**, 11 (1969).

⁷ McElroy, M. B., *J. Geophys. Res.*, **74**, 29 (1969).

⁸ Herman, J. R., and Chandra, S., *Planet. Space Sci.*, **17**, 815 (1969).

⁹ Barth, C. A., Wallace, L., and Pearce, J. B., *J. Geophys. Res.*, **73**, 2541 (1968).

Hoyle-Narlikar Quantization of Wheeler-Feynman Electrodynamics

Hoyle and Narlikar¹ (HN) have proposed a quantized version of the Wheeler-Feynman^{2,3} (WF) theory of classical electrodynamics. It is the purpose of this report to point out that the HN treatment of spontaneous emission deviates from the WF prescription. This is true even in the classical limit; however, in this limit the numerical effects of two different deviations cancel.

The WF theory is based on the postulates that charged particles interact via time symmetric ($\frac{1}{2}$ retarded + $\frac{1}{2}$ advanced) electromagnetic fields, and that there is no self interaction. The theory then takes into account the response of all charged particles in the universe to the field of each accelerated charge. The response field accounts for radiation reaction; it also re-establishes the full retarded field around each accelerated particle and defines a universal direction of time in which all the retarded potentials point.

The WF prescription for computing the response of the universe² to the field of an accelerated particle a is to let each charged particle b in the universe be excited by the full retarded and attenuated field of a , then let b react on a with one half its advanced field, unattenuated. (The full retarded and attenuated field is used for the action of a on b in order to allow for fields of particles other than a on b . No such allowance is necessary in the case of the action of b on a , because a summation on the contributions of all charged particles b in the universe is carried out explicitly.) The reaction field in the HN treatment is the full advanced field, attenuated.

HN quantize by Feynman's method of summation over all classical trajectories. The interaction term in

their Lagrangian is $\int_{\text{ret}}^{(a)} (b(t)) \cdot \dot{b}(t) dt$. This may be transformed

$$e \int_{\text{ret}}^{(a)} (b(t)) \cdot \dot{b}(t) dt = 2e^2 \iint \delta((a(t') - b(t))^2) \dot{a}(t') \cdot \dot{b}(t) dt' dt = e \int_{\text{adv}}^{(b)} (a(t')) \cdot \dot{a}(t') dt' \quad (1)$$

The reaction of b on a is therefore automatically the full advanced field. (We adopt the notation where a stands for the four-vector position of particle a . The middle expression in equation (1) describes retarded or advanced interaction according to the relative position of a and b . HN choose a segment of the world line of particle a and in the vicinity of its future light cone a segment of the world line of particle b . This choice makes the action of a on b retarded and the action of b on a advanced.) Because attenuation is introduced into the interaction before the summation on classical trajectories is completed, however, the reaction of b on a is also attenuated.

In the classical limit, the summation over all classical trajectories may be replaced by the use of the trajectory corresponding to stationary action. When this is done,