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PLASMA EXPANSION LAYER IN THE VENUS INNER IONOSHEATH

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ABSTRACT

We present plasma, magnetic field, and electric field data of the Pioneer Venus Orbiter (PVO) showing that the shocked solar wind in the Venus inner ionosheath exhibits flow conditions substantially different from those in the outer ionosheath. In particular, the plasma density is seen to drop significantly to low values within a layer adjacent to, and downstream from, the planet's ionopause. This change is not seen to develop gradually as the PVO moves into that region of space but occurs abruptly across a well-defined transition which extends downstream along the flanks of the Venus ionosheath. We explore the implications that these observations have in regard to the character of the interaction process between the shocked solar wind and the ionospheric plasma. It is argued that the existence of a sharply bounded region in the inner ionosheath within which the plasma density is severely depressed is consistent with the existence of friction processes at and near the ionopause. Plasma perturbations generated at this latter boundary, and distributed downstream through the ionosheath flow, may be responsible for the change of properties exhibited by the solar wind plasma in the inner ionosheath.

INTRODUCTION

Despite over 25 years of continued experimental and theoretical research of the Venus plasma environment there are still important features of the shocked solar wind that have not been properly identified and hence that have not been suitably incorporated to current descriptions of the local flow conditions. A particularly notable example is a plasma transition present along the flanks of the Venus ionosheath in the region adjacent to, and downstream from, the Venus ionopause. Across this transition the shocked solar wind experiences important changes which lead to an effective deceleration and expansion of the plasma in the inner ionosheath.

Even though this transition was identified in the plasma data obtained during the 1967 Mariner 5 Venus fly-by /1,2/, and was further reported from measurements conducted with the Venera 9 and 10 orbiters /3,4/, little has been learned in a statistical sense about its geometric and physical properties. Much of what is known in this respect derives mostly from recent studies of the electric field and plasma data of the PVO /5,6/, and further efforts /7/ are under way to include the magnetic field data. Here we report on what has been learned on the changes of the plasma density that the solar wind experiences across the intermediate transition both, in the case studies reported so far and as a result of the statistical examination of the PVO data. We will argue that there is now abundant information which confirms the presence of that transition as a steady state feature of the Venus ionosheath and that the PVO data shows variations consistent with those inferred from the Mariner 5 measurements.

THE MARINER 5 AND VENERA 9-10 PLASMA DATA

There is in the early report of the Mariner 5 measurements of the Venus plasma environment /1/ an extensive discussion on the plasma transitions identified in that spacecraft's transit near Venus. The authors of that report noted that in addition to the inbound and outbound crossing of the planet's bow shock there is evidence of an additional transition embedded deep within the ionosheath (shocked solar wind) region. Profiles of the plasma parameters and magnetic field intensity recorded as the spacecraft approached Venus from the wake and exited upstream from it are reproduced in Figure 1. These show a bow shock crossing (at t = E – 160 min, inbound, and at t = E + 20 min, outbound, E being the time of closest approach) across which the bulk speed is lower in the downstream side while the plasma density, the thermal speed, and the magnetic field intensity are higher in that side of the transition. A second transition (at t = E – 100 min, inbound, and at t = E + 5 min, outbound) is also evident in the behavior of these parameters. Here the bulk speed begins a further decrease in the inner ionosheath and the thermal speed a further increase in that region. Unlike at the bow shock, however, the plasma density and the magnetic field intensity are lower in the downstream side. The changes in these two latter parameters indicate that the flow experiences locally an expansion rather than a compression.

The unexpected changes experienced by the shocked solar wind at the inner (intermediate) transition led to arguments regarding the possibility that the features identified in the solar wind–Venus interaction region may be better described in terms of local density fluctuations (analogous to cometary tail rays). In this view /8/ the density and magnetic field features may reflect time variations of the interaction process rather than a steady state situation. In any case, in the initial Mariner 5 report /1/, and in the literature that derived from it /9/, emphasis was placed in the marked decrease of the density and magnetic field intensity seen across it; a variation that was believed could have resulted from the entry of the solar wind flow into the planet's wake. For this

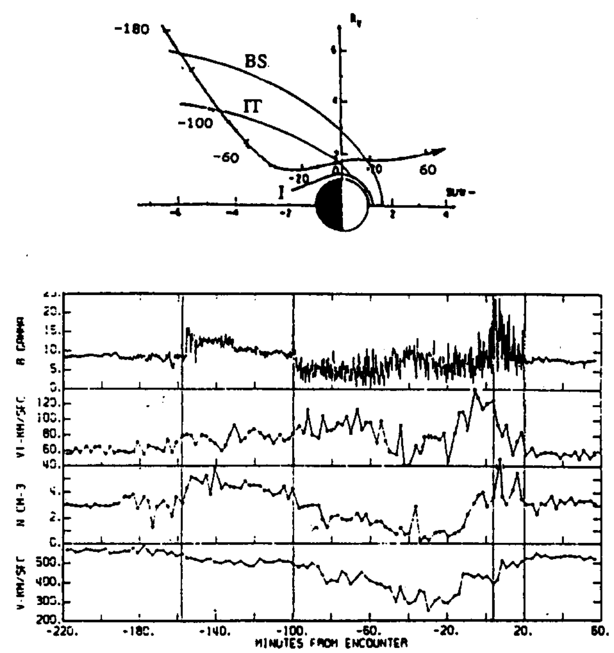

Fig. 1. (upper panel) Trajectory of the Mariner 5 spacecraft during its Venus fly-by in 1967 projected on a plane in which the vertical coordinate is the distance to the Sun–Venus line (the curves labeled "BS", "IT" and "I" indicate, respectively, representative shapes for the bow shock, the intermediate transition and the ionopause). (lower panel) Magnetic field intensity, Thermal speed, density, and bulk speed of plasma fluxes detected along the Mariner 5 trajectory near Venus (from /2/).

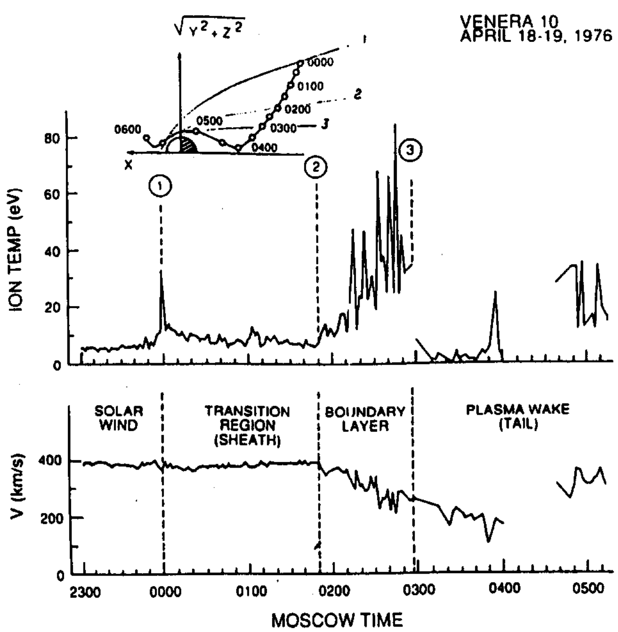

Fig. 2. Ion temperature and flow speed measured by the Venera 10 spacecraft as it entered the Venus wake and moved toward the planet on April 19, 1976 (from /4/).

reason that feature was addressed as a strong rarefaction wave which marks the outer extent of the flow perturbed by that process. It should be noted, however, that in a later publication /2/ it was pointed out that the higher plasma temperatures that characterize the plasma downstream from such a rarefaction wave hinder that interpretation; namely, a gas filling-in the wake behind a body is expected to cool off rather than to exhibit higher temperatures.

The Venera 9 and 10 plasma data /3,4/ showed plasma changes that are, in general, consistent with the Mariner 5 results. A useful example is reproduced in Figure 2 for the April 19, 1976 pass of the Venera 10 through the Venus near wake. As that spacecraft approached the planet there is clear evidence of a bow shock crossing (at ~ 0000 MT, Moscow Time) in the ion temperature and bulk speed profiles. As in the Mariner 5 encounter a second plasma transition can be identified deep within the ionosheath (at ~ 0150 MT). The anti correlation between the sudden variation of the plasma temperature and the flow speed seen across this transition is the same as that observed in the Mariner 5 fly-by and, as in that case, reveals that the decrease of the bulk velocity may indeed be very significant. Equally important to this consideration is the fact that the region where the second transition is located along the trajectory of the Venera 10 is equivalent to that in the Mariner 5 trajectory where the intermediate transition was observed.

Despite these consistencies no further comparisons were made with the Mariner 5 results partly because no information on the variations of the plasma density and magnetic field across the second (inner) plasma transition was presented in the Venera reports in which that transition was discussed. Thus, prior to the PVO experiment the only data suggesting an expansion process in the Venus inner ionosheath came from the Mariner 5 fly-by measurements.

PVO ELECTRIC FIELD AND PLASMA DATA

A substantial increment in the identification of the intermediate transition as a steady state feature within the Venus ionosheath was achieved through the analysis of the PVO electric field and plasma data. Through a technique based on the comparative examination of the signals recorded in the 30 kHz channel of the electric field detector and the energy spectra of plasma fluxes measured with the plasma instrument it is possible to identify short scale variations in the plasma density within the ionosheath flow. In particular, the 30 kHz channel is suitable for measuring plasma (Langmuir) oscillations at the local plasma frequency when the density is ~ 10 cm^{-3} /10-12/, as is usually the case in the freestream solar wind. The use of the plasma and the electric field data to examine density variations in the Venus plasma environment was first described in /5/ for the conditions observed in the inbound pass of orbit 80 of the PVO and is illustrated in Figure 3. The top panel shows the PVO trajectory on a plane similar to that of Figures 1 and 2, except that both the inbound and the outbound passes are shown in the same quadrant.

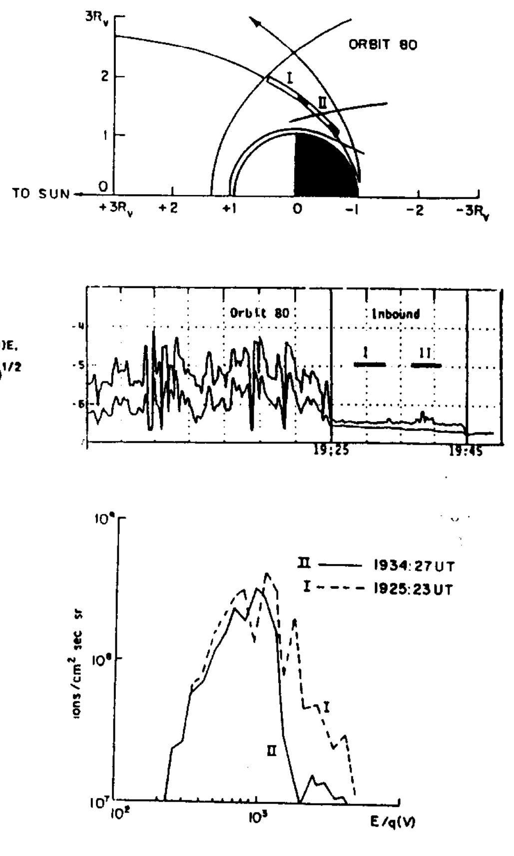

Fig. 3. (top panel) Trajectory of the PVO during orbit 80 projected on one quadrant of a plane in which the vertical coordinate is the distance to the Sun-Venus axis. (middle panel) Signals recorded in the 30 kHz channel of the electric field detector of the PVO during the inbound pass of orbit 80. (lower panel) Ion energy spectra measured with the PVO plasma instrument in the same pass (from /5/).

The electric field signature recorded with the 30 kHz channel (middle panel) shows high activity upstream from the bow shock (indicated by the vertical line at 1925 UT). This response is consistent with the detection of plasma oscillations at that frequency under typical ~ 10 cm^{-3} solar wind density values. Downstream from that transition the flow becomes compressed and the local plasma frequency occurs above the response range of the 30 kHz channel. As a result no electric noise is observed in that region. We note, however, that deep within the ionosheath (at ~ 1938 UT in the pass shown in Figure 3) there is evidence of a brief burst of additional electric field noise in that channel. These electric signals, which are detected prior to the crossing of the ionopause (marked by the vertical line at 1945 UT), imply that the local plasma density may have again become suitable for the generation of plasma waves near 30 kHz. Thus, it is possible that these signals represent oscillations at the plasma frequency which were produced by the sudden decrease of the plasma density from > 10 cm^{-3} values to < 10 cm^{-3} values.

The sudden expansion of the plasma in the inner ionosheath, which is suggested by these concepts, can be further explored by examining the PVO plasma probe data. These are reproduced in the bottom panel of Figure 3 where the two ion energy spectra recorded as the PVO traversed the ionosheath in the inbound pass of orbit 80 are presented. The ion spectrum labeled I (initiated at 1925:23 UT) was recorded while the PVO was in the outer ionosheath. The second ion spectrum (initiated at 1934:27 UT) began as the PVO moved to the inner region of the ionosheath and exhibits a different shape. Most notable is the fact that despite having a low energy buildup similar to that of the first spectrum the second spectrum displays a very strong sudden drop of the particle flux intensity at around 1 keV/q. This dramatic decrease of the flux intensity occurs between 2 neighboring energy steps and involves nearly a one order of magnitude difference in the values recorded. Very low intensity plasma fluxes are measured at higher energies thereby resulting in a very unusual particle flux distribution with a strongly depressed high energy tail. A dominant aspect of these measurements is the fact that the severe drop of the particle flux intensity took place very nearly at the time when the brief ionosheath 30 kHz electric field bursts were recorded (middle panel in Figure 3). Consequently the data of both, the plasma probe and the electric field instrument, are consistent with a sudden plasma density decrease detected as the PVO moved into the inner ionosheath in that orbit. This variation is in agreement with the crossing of a plasma transition whose signature is compatible with that inferred from the Mariner 5 measurements (in both cases there is evidence for the rarefaction of the inner ionosheath plasma fluxes downstream from Venus).

Analyses similar to that conducted for the data of orbit 80 have also been carried out for other PVO orbits. These show correlations between the electric field and the plasma data that are also in agreement with what was described above. An example which in many ways provides supplementary information to that of orbit 80 is provided by the measurements conducted in the outbound pass of orbit 60. These are reproduced in Figure 4 with the same format of Figure 3. In this case the brief 30 kHz electric field bursts detected in the ionosheath occur between two different energy scans of the plasma instrument. The energy spectrum labeled II (initiated at 2032:47 UT) shows strong peak fluxes characteristic of the outer ionosheath. By contrast the energy spectrum labeled I (initiated at 2023:44 UT) contains peak fluxes significantly smaller than those of the second spectrum. The fact that the first energy spectrum was recorded downstream from the location where the 30 kHz bursts were measured (at 2030 UT - 2032 UT) is consistent with the contention that the latter marks the sudden rarefaction of the ionosheath plasma fluxes. Thus the nearly one order of magnitude difference between the peak flux intensity measured in both spectra may be indicative of the rarefaction that the shocked solar wind experiences at the intermediate transition.

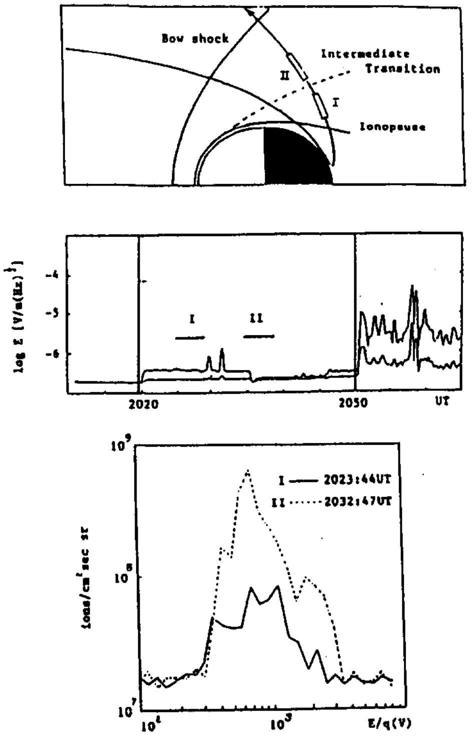

Fig. 4. (top panel) Trajectory of the PVO during orbit 60 projected on one quadrant of a plane in which the vertical coordinate is the distance to the Sun-Venus axis. (middle panel) Signals recorded in the 30 kHz channel of the electric field detector of the PVO during the outbound pass of orbit 60. (lower panel) Ion energy spectra measured with the PVO plasma instrument in the same pass (from /6/).

While it is not always possible to find in the PVO plasma data information on the energy distribution of the particle fluxes in the inner ionosheath we have found the 30 kHz electric field bursts to be consistent markers of the flow structure in the inner ionosheath. These features have been identified in a large number of PVO passes with varying degree of intensity and occurrence. In many instances they appear unmistakably as strong single events over an otherwise quiet background level. In others there are double or multiple rises which are nevertheless distinguishable from the background intensity. A further group is formed by passes in which the signals are weak and cannot always be clearly identified from other fluctuations in the electric field trace across the ionosheath. A sample of passes with some of the most distinguishable ionosheath bursts for both the inbound and the outbound legs of the PVO trajectory is presented in Figure 5. In all the cases shown the signals occur far away from the ionopause and thus can be safely assumed that they are not related to phenomena at that boundary. It should be noted, however, that in other orbits the electric field bursts are sometimes located very close to the ionopause and thus it is difficult to distinguish the origin of the feature.

The abundance of cases in which the 30 kHz electric field bursts appear as a separate and well developed structure of the Venus' ionosheath provides the best evidence available of the presence of the intermediate plasma transition as an additional steady state feature of that region of space. This conclusion is further supported by the peculiar distribution of PVO locations where such bursts are detected as depicted in Figure 6 for both the inbound and the outbound passes. It is to be noted that despite a certain dispersion of the PVO position (particularly in the outbound passes) there are many cases which cluster in a fairly small region of the ionosheath. That region extends across and downstream from the terminator along the flanks of the ionosheath and can be extrapolated downstream to a region which occurs in the general area where the "rarefaction wave" of the Mariner 5 data was identified. Thus even though the Mariner 5 (and the Venera) data on one hand, and the PVO data on the other, apply to different downstream distances from Venus, they are consistent with the presence of one same plasma feature embedded in the Venus ionosheath.

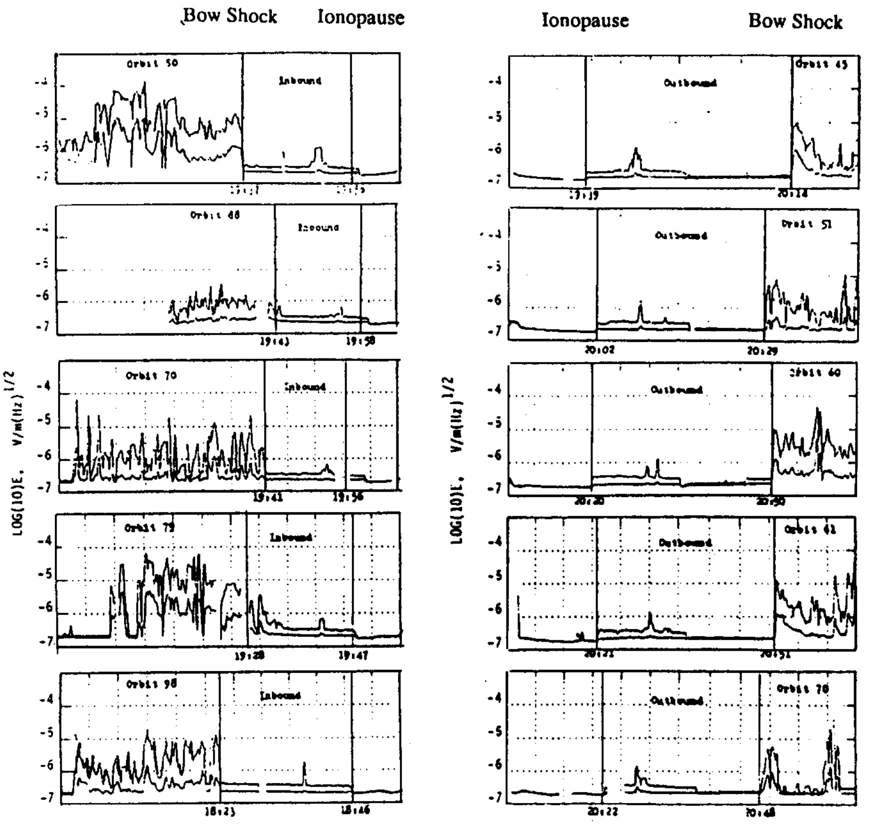

Fig. 5. Examples of PVO electric field data with strong 30 kHz bursts detected in the Venus ionosheath (the vertical lines indicate the bow shock and the ionopause crossings).

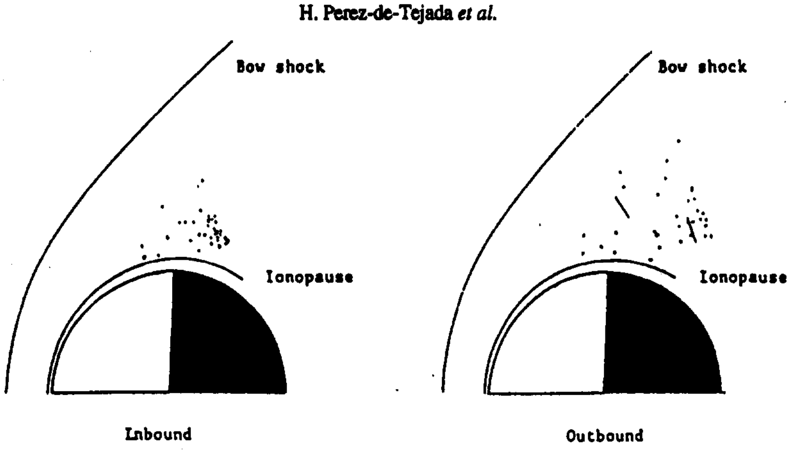

Fig. 6. PVO position (projected on the same plane as Figure 3) at the time when strong electric field 30 kHz bursts were detected in 67 passes through the Venus ionosheath (from /6/).

PVO MAGNETIC FIELD DATA

As noted earlier the Mariner 5 measurements contain evidence that the interplanetary magnetic field also experiences noticeable changes across the intermediate transition. That data indicate that in the downstream side of this transition the intensity of the magnetic field is lower, more irregular, and its direction shows frequent fluctuations /1/. A rotation of the magnetic field vector at the time when the 30 kHz bursts were detected in the Venus ionosheath was noticed in the electric field data of the PVO in orbit 80 (Figure 3) /5/. Independent evidence of a magnetic field rotation in association with specific features of the Venus ionosheath was later reported from the analysis of the magnetic field and plasma data of two PVO orbits in the far Venus wake /13/. In this case the magnetic field vector is seen to exhibit an orientation more nearly aligned to the Sun-Venus line in that region of the Venus inner ionosheath where the velocity field shows a strong transverse gradient. No substantial change in the magnetic field intensity was identified, however, in any of these two later studies and thus the observed variation differs from that reported in the Mariner 5 experiment.

A more extensive investigation of the PVO magnetic field data /7/ has revealed that a rotation of the magnetic field to a direction more nearly aligned to the Sun-Venus axis, and a substantial decrease of its intensity, are changes seen frequently in the inner ionosheath across the intermediate transition. In some cases these changes occur suddenly but in others either the direction or the magnitude of the magnetic field, or both, change gradually. From a study of 83 passes of the PVO through the Venus ionosheath with strong 30 kHz electric field bursts it was found that these variations of the magnetic field are present in nearly 50 % of the cases examined. In many other passes there is also evidence of the magnetic field rotation but an increase (rather than a decrease) of the magnetic field intensity in the inner ionosheath accompanies that variation.

An example that best represents the magnetic field signatures recorded at the time when the 30 kHz electric field bursts are detected in the Venus ionosheath is provided by the inbound and outbound passes of the PVO in orbit 87 reproduced in Figure 7. We note, first of all, that strong electric field signals in the 30 kHz channel (upper panel) are present upstream from both, the inbound and the outbound bow shock crossings (at 1905 UT and at 2007 UT, respectively). Downstream from both crossings no electric signals are detected until ~ 1920 UT (inbound) and ~ 1953 UT (outbound) when intense bursts are again measured. This behavior is analogous to that described earlier from the inbound pass of orbit 80 (Figure 3) and the outbound pass of orbit 60 (Figure 4) and, as shown below, is also consistent with a sudden expansion of the shocked solar wind plasma at the intermediate transition. In both, the inbound and outbound passes, the strong 30 kHz ionosheath bursts occur well upstream from the ionopause crossings (at 1928 UT inbound, and at 1944 UT outbound, respectively) and thus are not likely to result from wave activity at that boundary. This is better appreciated in the 2-dimensional projection of the PVO trajectory in orbit 87 shown in the upper panel of Figure 8 together with representative shapes for the bow shock, the ionopause, and the intermediate transition, suitable to both the inbound and the outbound passes in that orbit.

In the outbound pass of orbit 87 the 30 kHz bursts at 1952–1953 UT occur at the same time the magnetic field intensity drops from about 30γ upstream to about 10γ downstream (upper panel of Figure 7). This change in the magnetic field intensity is, at least, comparable to that observed across the bow shock and leads to values even smaller than those in the freestream solar wind. The direction of the magnetic field vector shows at this time a strong rotation from a preferred y-z orientation upstream (on the plane perpendicular to the Sun-Venus line) to a direction nearly coincident with the x-axis downstream (lower panels). This strongly draped orientation of the magnetic field lines persists throughout the region between the intermediate transition and the (outbound) ionopause crossing, and is very different from that present in the outer ionosheath (after 1953 UT). In the inbound pass the behavior of the magnetic field across the intermediate transition is entirely different. Instead of marking a decrease of the magnetic field intensity upstream to low values downstream, the 30 kHz electric bursts occur in a region where the profile of the magnetic field intensity changes its slope. Upstream from that location there is a general decrease of this quantity as the PVO moves inbound through the ionosheath (upper panel in Figure 7). After ~ 19:21 UT, however, the profile levels-off and then increases slightly downstream. In addition, since at this time the B_x component (directed along the Sun-Venus line) increases while the transverse B_y component decreases, the magnetic field vector also acquires a draping configuration in that region of space. However, this variation occurs more gradually, and is not as accentuated, as in the outbound pass.

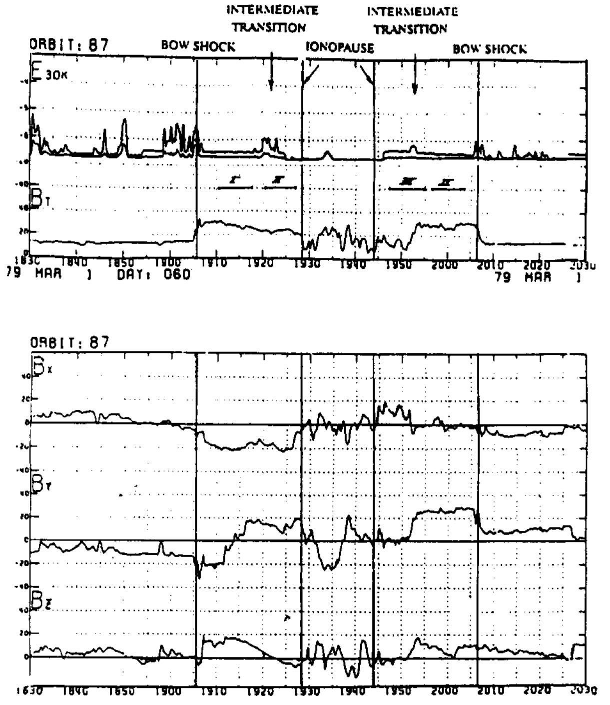

Fig. 7. (upper panel) Electric field noise detected with the 30 kHz channel of the electric field detector of the PVO together with the magnetic field intensity measured in the inbound and outbound passes of orbit 87. (lower panels) Magnetic field components B_x, B_y, and B_z measured during the same passes [The bow shock and ionopause crossings are indicated by the vertical lines at ~ 1905 UT and ~ 1928 UT (inbound) and at ~ 2007 UT and at ~ 1944 UT (outbound). The intermediate transition crossings are indicated by the arrows at ~ 1921 UT (inbound) and at ~ 1953 UT (outbound)] (from /7/).

The data of orbit 87 are particularly useful because they provide information that reveals, even more explicitly than that of orbits 80 (Figure 3) and 60 (figure 4) the sudden changes exhibited by the shocked solar wind across the intermediate transition. The two spectra measured in the inbound pass (shown in the left panel at the bottom of Figure 8) describe conditions similar to those usually seen upstream and downstream from that transition; namely, strong peak plasma fluxes in the outer ionosheath (spectrum labeled I) and weak peak plasma fluxes (and at lower energies) in the inner ionosheath (spectrum labeled II). These differences are analogous to those found in the outbound pass of orbit 60 (Figure 4) where a cycle of plasma measurements was also conducted before and after the brief 30 kHz electric field bursts are detected. More unusual, however, are the conditions recorded outbound in orbit 87 (right panel at the bottom of Figure 8). In this case the spectrum labeled IV (measured in the outer ionosheath) presents one main peak but the spectrum labeled III (measured closer to the planet) is peculiar in that it contains two main maxima. The two main peaks of this spectrum have flux intensities comparable to those seen, respectively, in the inner ionosheath (spectrum labeled II in the inbound pass) and in the outer ionosheath (spectrum labeled IV in the outbound pass) and thus appear to reflect the conditions present in both regions. What makes these measurements particularly important is the fact that the PVO plasma instrument scanned the energy range between both main peaks of spectrum III nearly at the time when the 30 kHz electric field bursts were detected. Thus, as it was the case in the inbound pass of orbit 80 (Figure 3), there is here a notable agreement in the timing of the sudden plasma expansion in the inner ionosheath as inferred from measurements conducted with different instruments of the PVO.

The two magnetic profiles seen in the inbound and outbound passes of orbit 87 (upper panel of Figure 7) are representative of those most often found in the data set examined so far. It is possible that they reflect the conditions present around different (magnetic) latitudinal regions of the Venus ionosheath. For example, the magnetic profile seen in the inbound pass may correspond to locations downstream from the magnetic barrier formed around the dayside ionosphere (in this case the enhanced magnetic field fluxes measured between the intermediate transition and the ionopause are due to that effect). On the other hand, the low magnetic field intensities measured in the outbound pass could result from a local expansion process around the magnetic poles of the Venus ionopause (these are the regions around which the interplanetary magnetic field slip over the planet). Support for this view is obtained from the orientation of the B_{yz} component (transverse to the Sun–Venus line) of the magnetic field present in orbit 87. This is reproduced in Figure 9 along the PVO trajectory as the spacecraft moved from the northern to the southern hemispheres. In the outbound pass the orientation of the B_{yz} component between the freestream solar wind (position a) and the intermediate transition (position b) is such that the PVO may have moved downstream from the southern magnetic polar region (as noted earlier a strong rotation of the magnetic field vector from a preferent x-direction in the inner ionosheath to the y and z directions in the outer ionosheath takes place at the intermediate transition in that pass). The same cannot be said about the inbound pass since, in this case, the B_{yz} component experienced a large gradual rotation between the corresponding positions a and b. Because of the strong magnetic field intensities recorded throughout that pass it is unlikely that the PVO traversed the region downstream from the northern magnetic pole but, instead, moved downstream from the magnetic barrier that forms at lower magnetic latitudes around the dayside ionosphere.

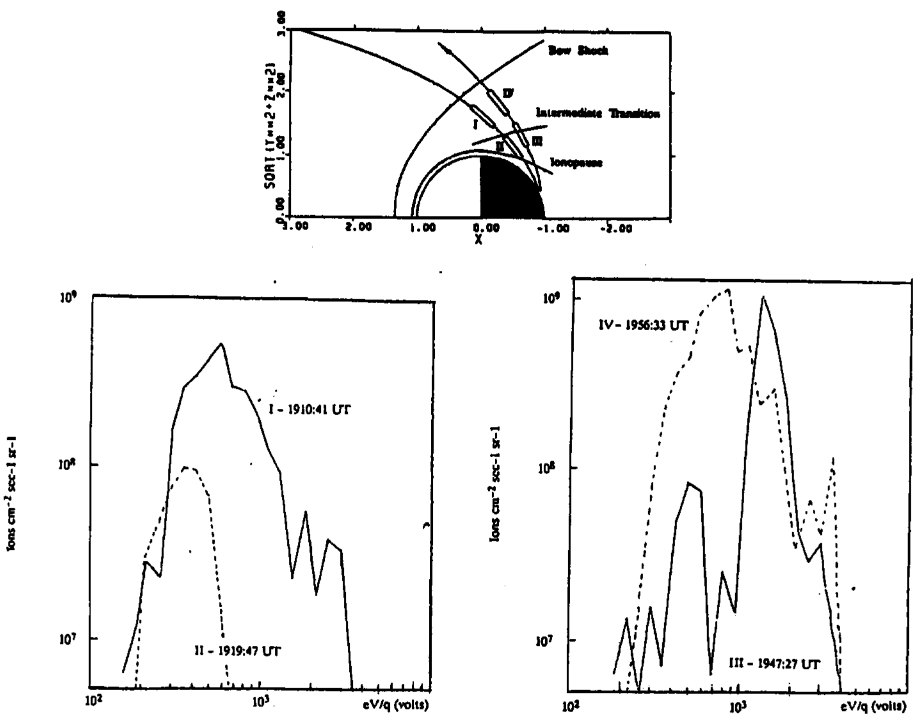

Fig. 8. (top panel) Same as Figure 3 for orbit 87. (Lower panels) Ion energy spectra measured with the PVO plasma instrument during the two energy scans completed in the inbound (left panel) and outbound (right panel) traversals of the Venus ionosheath in orbit 87 (The starting time of each scan is indicated in the figure) (from /7/).

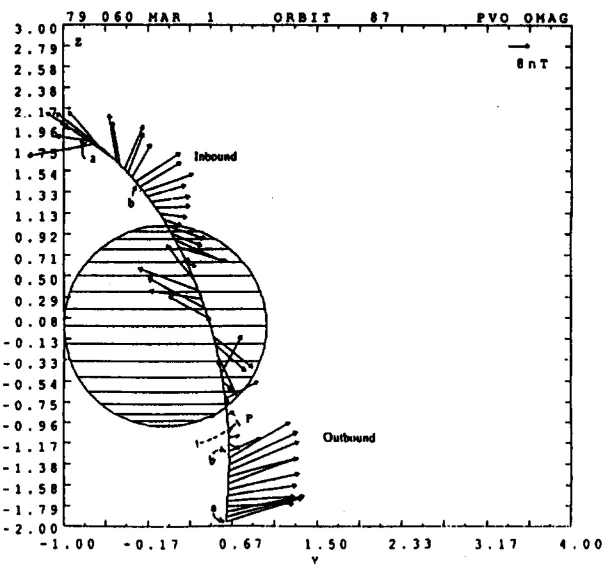

Fig. 9. Magnetic field vectors measured along the trajectory of the PVO during orbit 87 projected on the y-z plane (transverse to the Sun-Venus axis). The positions labeled a and b in both the inbound and the outbound passes correspond, respectively, to the freestream solar wind and near the region where the 30 kHz electric field bursts are detected in the inner ionosheath (the arc section labeled P indicates the approximate location of the magnetic polar region suitable to the outbound pass) (from /7/).

DISCUSSION

The persistent presence of a transition marking sudden changes in the plasma properties within the Venus ionosheath forces important constraints on the interpretation of the processes that operate in that region. The viability of chemical phenomena (mass loading and charge exchange collisions) to account for the observed behavior should be evaluated in light of the peculiar nature of the changes observed. One can distinguish at least 2 different aspects of the problem that deserve consideration. On the one hand the basic notion that the effects of chemical processes /14,15/ become increasingly more important as the solar wind moves toward regions where the planetary neutral population is denser implies configurations where the flow conditions change gradually, not suddenly. Within the context of these phenomena it would therefore seem more fitting to see that the deficit of solar wind momentum (given by the decreased flow speeds) begins gradually at far away distances from the planet and becomes increasingly more important closer to its atmosphere/ionosphere. Most possibly this type of variation applies adequately to the far reaches of the Venus plasma environment, even upstream from the bow shock, where no other momentum-removing processes may be operative. However, there is no apparent reason why the more dense neutral populations of the planet's exosphere close to the planet should produce a sudden change in the properties of the oncoming flow and thus account for the observed plasma transition in the inner ionosheath. Detailed measurements of the mass loading process, particularly upstream from the planet, are necessary to further examine this issue.

Equally critical to the above argument is the fact that the intermediate transition has now been identified at both close and far away distances from Venus (The lower distances being given by the PVO observations at < 2000 km from the planet and the larger ones by the Mariner 5 and the Venera 9-10 measurements at ~ 10 000 km downstream). This means that the processes that produce it may not be particularly dependent on the local density of the neutral populations since the phenomenon occurs when the local neutral density is both relatively high (in the region examined by the PVO) or very low (at the distances probed by the Mariner 5). Under this circumstance it is difficult to accept that high neutral densities would be required to produce the transition or, alternatively, to understand why the phenomenon is also present when the local neutral densities are low.

Rather than resulting from changes produced locally on the flow by the neutral particle populations the intermediate plasma transition seems to require a non-local source such as would be expected from the continuous transit of plasma disturbances generated upstream from the point of observation. In this case that plasma feature would be present independent of the local density of the neutral populations and accuse a definite association to a specific region of the Venus plasma environment from which the disturbances originate. This latter constraint suggests a property commonly associated with friction phenomena; namely, the distribution of perturbations produced by an obstacle immersed in a fluid. The manner in which this is accomplished in conventional hydrodynamics /16/ is illustrated schematically in Figure 10 for a supersonic flow past a flat plate. We note that in addition to a front shock that arises from the nose of the obstacle there is a second transition, downstream from the shock, which also flares out from the obstacle. This second transition represents the outer boundary of a region, adjacent to the obstacle, influenced by the friction process. Within this region the flow moves slower as a result of the retardation imposed on it by the obstacle; with a fraction of the lost momentum having been delivered to the obstacle itself. The outer boundary of the friction layer separates two different regions within the shocked flow and appears as a clearly distinct mark in the flow properties. Higher plasma temperatures are expected in the vicinity of the obstacle because of the dissipated energy associated with the friction process. This, in turn, produces the local expansion of the gas so that its pressure matches that of the flow outside the friction layer. The region adjacent to the obstacle is, therefore, characterized by gas densities significantly lower than those present outside the friction layer.

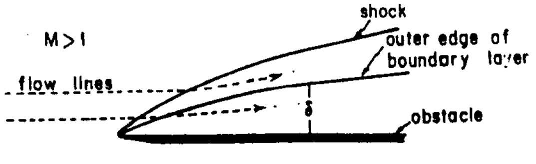

Fig. 10. Schematic diagram showing the structure of a supersonic viscous flow past an obstacle as it is known in hydrodynamics. In addition to a bow shock there is a second transition marking the outer boundary of a friction layer adjacent to the obstacle (from /16/).

On the basis of these concepts it is therefore possible to argue that the intermediate transition of the Venus ionosheath may, in fact, represent the outer extent of a friction layer adjacent to the Venus ionopause. The plasma within this layer should be strongly affected by perturbations generated at the ionopause and distributed to the ionosheath downstream. While there is a general qualitative resemblance in the geometry and physical properties of the flow in the inner ionosheath with those expected in the equivalent hydrodynamic situation, it is important to point out that the hydrodynamic description requires the existence of suitable mechanisms transferring momentum across the Venus ionosheath. This is an important issue since the collisionless character of the solar wind hinders a simple interpretation of the manner in which momentum is exchanged among the various particle populations. A viable possibility, based on momentum scattering interactions of planetary ions picked up by the solar wind with local turbulent wave fields /17,18/, has been recently proposed /19/ in connection with the conditions seen at the Mars magnetopause where a similar transfer of solar wind momentum seems also to be required /20/. In this view the pickup ions deliver, through wave-particle interactions with the local fields, a fraction of the solar wind momentum to the slower moving particles within the friction layer and in the ionosphere. The effects of this process should modify the distribution and dynamics of the particles in both, the ionosheath and in the ionosphere, and produce the peculiar character of the shocked solar wind between the intermediate transition and the ionopause. More extensive analyses are still required, however, to better substantiate the applicability of this concept.

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