tense impulsive bursts near 1959, and possibly those associated with the density irregularities at 1956:30 and 1958:30.) Figure 2 also shows that the nominal upper boundary of the ionosphere (at approximately 1952 inbound and 2006 to 2007 outbound) was not marked by an abrupt onset of continuous 100-Hz ionosheath whistler mode turbulence, although the density gradient starting at 2006:30 and the one at 2009 were associated with enhanced turbulence levels. The lack of continuous ionosheath noise is understandable because on 19 February 1977 the top of the ionosphere was not adjacent to shock solar wind plasma (the orbiter plasma probe detected ionosheath plasma before the interval 1942:30 to 1945:08 and after the interval 2013:05 to 2018:59) and the ionosheath whistler mode waves were not in direct contact with the nightside ionosphere (*12*). Thus, if energy deposition is required to explain the structure of the ionosphere at night, a mechanism other than the one described in Fig. 1 must be operating here. In this connection we note that the 5.4-kHz and 730-Hz panels in Fig. 2 show smooth increases in wave intensity near periapsis. Here the electron cyclotron frequency was about 850 Hz, the electron plasma frequency was above 250 kHz, and the 5.4-kHz observations could not represent detection of electromagnetic waves. However, for an O^+ density of (1 to 2) × 10^3 cm^{-3}, electrostatic ion sound waves with 5.4 kHz could be excited (*13*). Further studies of these high-frequency nightside wave observations are in progress.

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Initial Pioneer Venus Magnetic Field Results: Nightside Observations

Abstract. *Initial observations by the Pioneer Venus magnetometer on the nightside of Venus frequently reveal moderately strong fields from 20 to 30 nanoteslas. However, there is little evidence that these fields arise from an internal dynamo since they are mainly horizontal and vary from orbit to orbit. Determining a precise upper limit to the intrinsic moment awaits further processing. This limit is expected to be much less than 10^{22} gauss-cubic centimeters.*

Venus is not only Earth's nearest neighbor, but it is also the planet most similar to Earth in size. Thus, we might expect that Venus would be similar in many respects to Earth. One important difference, however, is that Venus rotates much more slowly than Earth: a Venus sidereal day equals 243 Earth days. From dimensional considerations we would expect the magnetic moment of Venus to scale as the frequency of rotation and the fourth power of the radius of the core (*1*). If we assume that the core radius is 0.5 Venus radii (R_V), then the expected moment is about 2 × 10^{23} gauss-cm^3 or 2 × 10^{-3} of that of Earth. Busse's more sophisticated magnetohydrodynamic treatment gives a similar result (*2*). Although much smaller than the terrestrial moment, such a magnetic field should be easily detectable by an orbiting spacecraft at low altitudes, especially in the wake region behind the planet. Thus, one of the prime objectives of the Pioneer Venus orbiter magnetometer investigation is to search for an intrinsic magnetic field.

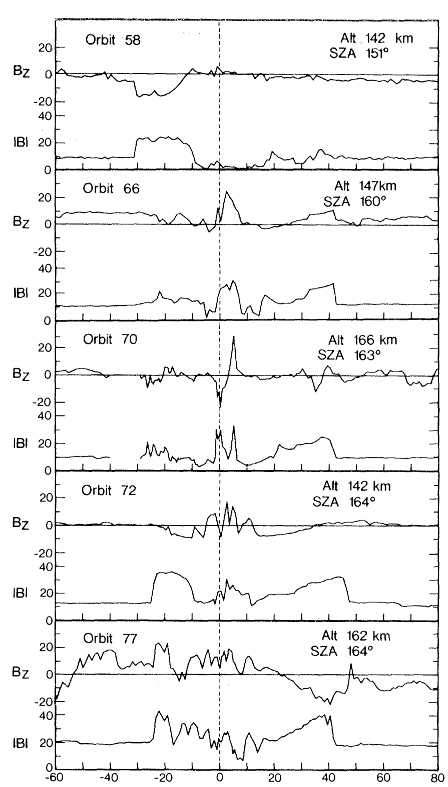

Fig. 1. Average magnetic field strength |*B*| and field parallel to the satellite spin axis B_Z for orbits 58, 66, 70, 72, and 77. Orbit 71 passed closest to the antisolar point. Units are nanoteslas.

This report summarizes our initial observations of the magnetic field on the nightside of Venus where any weak intrinsic field should be confined by the solar wind flow. In an earlier report we discussed our initial dayside observations including the bow shock locations, the ionopause, and ionospheric flux ropes (*3*). As before, the results presented here were obtained from "quick look" data. These data now contain inertial reference information, but timing errors limit the directional accuracy to about 5° to 10° depending on telemetry rate. These errors will not be present in the final processed data (*4*).

The magnetic field of Venus has been measured on Mariner 5, Venera 4, Venera 9, and Venera 10. Mariner 5 passed close to the wake of Venus and saw a steady field directed toward Venus north of the ecliptic plane (*5*). Venera 4 penetrated to about 200 km on the nightside just behind the terminator. Venera 4 detected little change in the field magnitude (*6*), but the variation in the vector components was suggestive of a possible planetary field with a northward moment

(7). The upper limit to the Venus magnetic moment consistent with these data was 6.5×10^{22} gauss-cm³. Venera 9 and Venera 10 orbited Venus and detected a magnetotail consistent with a moment of about 4×10^{22} gauss-cm³. However, near the planet the direction of the field in the wake region appeared to depend on the direction of the magnetic field in the solar wind consistent with an induced ionospheric field (8). Finally, as noted in our earlier report (3), the magnetic field strength in the dayside ionosphere is very low. Thus, either Venus has a very weak magnetic moment or any planetary field diffusing into the ionosphere is very effectively swept to the nightside by ionospheric flows. In any event, the magnetic moment of Venus is much less than we would expect from a simple scaling of the terrestrial moment.

Figure 1 shows 1-minute averages of the magnetic field magnitude and the field component parallel to the spin axis for five orbits crossing the Venus wake region. The solar zenith angle (SZA) and altitude of periapsis are indicated for each orbit. Periapsis is at 17°N, and the orbit is inclined 105° to the ecliptic plane. Orbit 71 passed closest to the antisolar point.

The region of rather constant field magnitude on each orbit is the solar wind. The often sudden increase in field strength at about 30 minutes before periapsis and the decrease at about 40 minutes after periapsis correspond to the crossings of the Venus bow shock. As evident in orbits 58 outbound, 66 inbound, and 70 inbound, the bow shock is not always clearly defined in the magnetic records. These instances are probably cases of parallel or nearly parallel shocks, but we have not yet examined these shocks in detail. As the spacecraft proceeds toward periapsis after crossing the bow shock at these local times, the magnetic field strength generally decreases in magnitude, sometimes smoothly and sometimes irregularly, in contrast to the increase as the planet is approached (3). However, when the spacecraft crosses near the center of the wake region, the magnitude often increases again, to rather substantial (~ 30 nT) values.

This region in the center of the wake is where one would expect any weak intrinsic field to be detected. However, the variability of the field in this region in both magnitude and direction suggests that it is not planetary in origin. For example, on orbit 58, which passed within 21° of the antisolar point, there is no significant magnitude enhancement. Furthermore, from orbit to orbit the direction of the field as indicated by the sign of the spin axis component B_Z is variable.

Figure 2 shows high-resolution (two samples per second) measurements through periapsis on orbit 66. The coordinate system is approximately the solar ecliptic system. The spacecraft reached periapsis at 2009:11 UT (9), crossed the ecliptic plane at 2012:12 UT, and passed closest to the sun-Venus line 12 seconds later. These measurements show not only that the magnetic field is quite irregular on the nightside but also that the current sheets bounding fields of different directions can be quite thin.

Figure 3 shows 1-minute averages of the field for orbit 66 plotted along the trajectory. The coordinate system is such that the plane of the figure contains the Venus-sun line and the Venus-spacecraft line and hence rotates with the spacecraft. The magnetic field has been projected onto this plane. The distance from the center of the planet to the spacecraft is the actual radial distance. The angle from the Venus-sun line is the SZA or sun-Venus-spacecraft angle. This display is useful for cylindrically symmetric situations.

On this orbit the Pioneer Venus orbiter is inbound over the northern polar region along the lower trace in Fig. 3. Initially the field in the magnetosheath radiates away from the planet as if carried along by the magnetosheath flow and draped over the dayside of the planet. As the planet is approached, the field bends around the planet as if the flow were con-

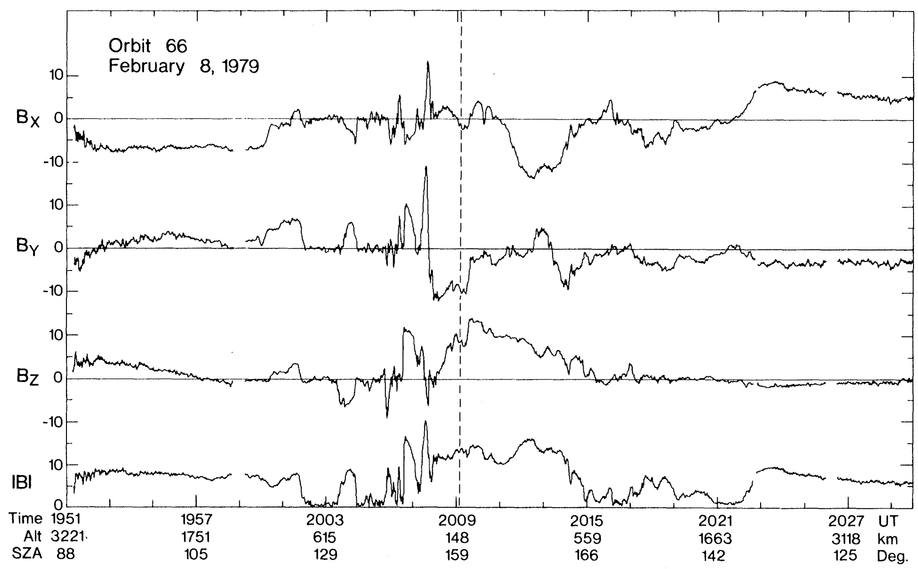

Fig. 2. High-resolution (two samples per second) magnetic field measurements for orbit 66. The dashed line designates periapsis. Vector components are in a coordinate system close to solar ecliptic coordinates. Units are nanoteslas.

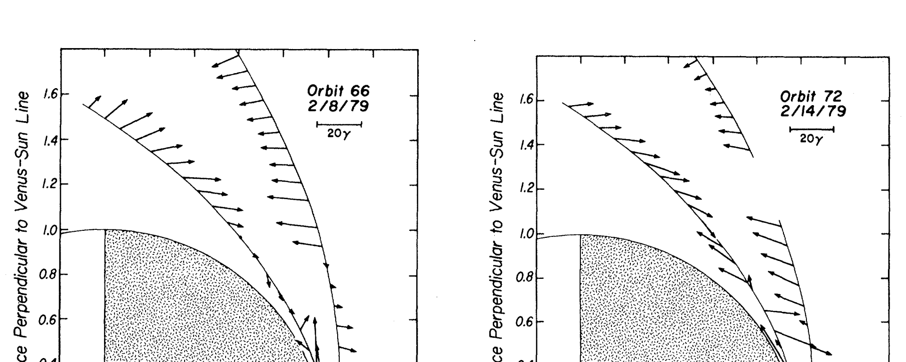

Fig. 3 (left). Magnetic field and spacecraft trajectory in solar cylindrical coordinates for orbit 66. The plane of the figure rotates about the Venus-sun line so that it always contains the spacecraft position (1 γ = 1 nT). Fig. 4 (right). Magnetic field and spacecraft trajectory in solar cylindrical coordinates for orbit 72.

verging into the Venus wake. Eventually the field strength decreases to very low values, but it increases later to quite large values near periapsis. Generally these field values are horizontal and do not appear rooted in the planet except in the region closest to the center of the wake. Outbound at higher altitudes the field is no longer horizontal at the same values of SZA as it was when the spacecraft was inbound; this result suggests that in this region the flow is not horizontal but more tailward away from the planet. Farther along the outbound leg the field reverses and becomes quite strong. The direction of the field in this display then follows the pattern of the inbound leg but reversed in direction. This pattern would be expected if the external field direction remained constant during the satellite's passage through the wake and these field lines were draped over the ionosphere. The opposite field directions seen in the center of the wake are therefore probably the remnants of some earlier magnetosheath field which had penetrated the ionosphere and been convected to the nightside, possibly in the form of flux ropes.

Figure 4 shows a similar display for orbit 72 during which the spacecraft penetrates closer to the wake axis than on orbit 66. Well away from the wake on both inbound and outbound passes the field directions suggest draping. Closer to the wake the pattern of the field vectors again suggests convergence of the flow into the night ionosphere. In the magnetic field there is no clear boundary between magnetosheath and ionospheric plasmas. However, there are distinct regions with different directions of magnetization. The existence of these differing field directions within the wake suggests that the field here is a remnant induced by earlier solar wind conditions. When the data for entire orbits become available, we will be able to determine when this field direction was impressed on the ionosphere.

Although there are strong magnetic fields on the nightside of Venus, there is little evidence that these fields arise from an internal dynamo. A Venus magnetic moment of 10^{22} gauss-cm^3 would give rise to a 10-nT polar field. If such a field were present, it would certainly be evident in displays such as Figs. 3 and 4. Instead, the field is mainly horizontal near the planet. Furthermore, the direction of the field in the wake on these orbits is opposite to that seen on the Mariner 5 and Venera 4 missions (*5*, *6*). A firm upper limit to the moment awaits a comprehensive study of all the nightside data, but it would certainly seem at this stage that such a limit will be much less than 10^{22} gauss-cm^3. The rapid convergence of the field toward the wake axis implies slow flows into the wake at low altitudes. The direction of the large fields near periapsis often differs from what we would expect, given the direction of the field outside of the ionosphere. Thus, these low-altitude wake fields appear to be remnants of some previously induced current. It seems improbable, because of their variability from orbit to orbit, that they are intrinsic fields.

Prior to the Pioneer Venus measurements, the Venus magnetic field appeared to be surprisingly weak. These measurements increase the gap between expectation and observation. It is most likely that at present Venus does not have an active magnetic dynamo. Since Venus rotates and most certainly has a liquid conducting core, the explanation probably lies in the fact that the magnetic Reynold's number is not high enough for dynamo action. This fact in turn suggests simply that the convective motion in the interior of Venus is not strong enough to generate a field. Weak convective motion could be due either to the present state of thermal evolution of Venus or to some chemical or physical difference between the interiors of Venus and Earth.

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Electron Observations and Ion Flows from the Pioneer Venus Orbiter Plasma Analyzer Experiment

Abstract. *Additional plasma measurements in the vicinity of Venus are presented which show that (i) there are three distinct plasma electron populations—solar wind electrons, ionosheath electrons, and nightside ionosphere electrons; (ii) the plasma ion flow pattern in the ionosheath is consistent with deflected flow around a blunt obstacle; (iii) the plasma ion flow velocities near the downstream wake may, at times, be consistent with the deflection of plasma into the tail, closing the solar wind cavity downstream from Venus at a relatively close distance (within 5 Venus radii) to the planet; (iv) there is a separation between the inner boundary of the downstream ionosheath and the upper boundary of the nightside ionosphere; and (v) during the first 4.5 months in orbit the measured solar wind plasma speed continued to vary, showing a number of high-speed, but generally nonrecurrent, streams.*

In this report we present additional (*1*) early results from the Pioneer Venus orbiter plasma analyzer experiment. Most of these results are based on the available real-time data. Least-squares reduction of the few data tapes we have received provided the ion flow velocities.

Our early Pioneer Venus observations (*1*) indicated that the solar wind interaction at Venus is dynamic and consistent with a solar wind ionosphere-atmosphere interaction. Recently, Intriligator and Smith (*2*) calculated that the atmospheric-ionospheric particle pressure at Venus [as measured by the Pioneer Venus orbiter experiments (*3*)] is sufficient to hold off the external solar wind. The implied primarily nonmagnetic planetary solar wind interaction is consistent with Pioneer Venus magnetic field measurements (*4*) and unlike the interactions at Earth or Jupiter.

In this report we further explore this interaction by presenting preliminary plasma electron and ion observations in the ionosheath and in the vicinity of the wake. Finally, since the solar wind–Venus interaction is very dynamic and since the configuration of the Venus ionosphere, on the sunward side at least, appears to be coupled to the external solar wind (*1*, *3*), we present the daily solar wind speeds from orbit insertion (4 December 1978) through 18 April 1979.

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