The Pioneer Venus Orbiter Plasma Analyzer Experiment

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Abstract—**The plasma analyzer experiment on the Pioneer Venus Orbiter was designed to determine the basic characteristics of the plasma environment of Venus and the nature of the solar wind interaction at Venus. The plasma analyzer experiment is an electrostatic energy-per-unit charge (E/Q) spectrometer which measures ions and electrons. There is a curved plate electrostatic analyzer system with multiple collectors. The experiment obtains the three dimensional plasma distribution function. Some of the scientific objectives of the instrument are briefly discussed, the general characteristics of the experiment are summarized, and some of the analyses based on the data are presented.**

I. Scientific Objectives

The Pioneer Venus Orbiter (PVO) plasma analyzer was designed to determine the basic characteristics of the plasma environment of Venus and the nature of the solar wind interaction at Venus. Previous observations on Venera 4, 6, 9, and 10 and on Mariners 5 and 10 ascertained some aspects of the interaction of the solar wind with Venus but many fundamental questions about the nature of this interaction remained unresolved [1].

Even the basic physical processes that govern the interaction of the solar wind with Venus were uncertain since it was not known whether or not the solar wind interaction was with a planetary magnetic field or whether the Venus interaction was a unique planetary interaction and that it was purely a solar wind–ionospheric interaction. Similarly, in the antisolar region downstream from the planet, the plasma properties and the nature of the physical mechanisms that significantly affect the environment were unresolved. Three possible configurations of this region are: a magnetotail similar to that of the earth's, a wake similar to that of our moon, or a region similar to that behind a comet. It is also possible that at Venus the configuration is different from these or perhaps a combination of these.

A. The Dayside Interaction

The PVO plasma analyzer was designed to determine the basic nature and variability of: the Venus bow shock, the change in the plasma parameters across the shock, the three-dimensional vector flow associated with the shocked plasma, the boundary between the shocked plasma and the ionosphere and other effects of the obstacle on the deflected plasma. In addition, it was anticipated that the results from the PVO plasma analyzer in conjunction with those from other PVO experiments would help to determine the effects of the deflected solar wind on the Venus ionosphere including its possible heating of the dayside ionosphere, its contribution to the nightside ionosphere, and generally its relation to the dynamics of the ionosphere.

B. The Downstream Interaction

The PVO plasma analyzer was designed to determine the basic nature and variability of: the plasma regimes in the region downstream of the planet, the possible exclusion or changes in shocked flowing plasma in this region, the downstream boundary between the shocked plasma and the other plasma regimes in this vicinity, and other characteristics of the configurations of the planetary environment in this vicinity. In particular it was anticipated that the results from the plasma analyzer experiment would indicate whether or not a magnetotail like that at the earth is present and/or a lunar-type wake is present or whether a different configuration is characteristic of this region. The plasma analyzer can also investigate such phenomena as substorms or the presence of a plasma sheet. The plasma analyzer was also designed to investigate the consequences downstream of a viscous-like solar wind–Venus interaction or other aspects of a direct interaction between shocked solar wind plasma and the ionosphere or the neutral atmosphere. In addition, it was anticipated that the results from the PVO plasma analyzer in conjunction with those from other PVO experiments would help to determine many other aspects of the planetary environment in this region. Moreover, the PVO orbit is particularly suitable for studying the average properties and variability of this region. The high inclination of the orbit enables the spacecraft to sample both the northern and southern regions downstream from the planet on a single pass and the very low altitude of periapsis should enhance the results of the PVO investigations.

II. Instrument Description

A. Description of the Analyzer System

The NASA Ames Research Center plasma analyzer on the PVO consists of a 90° quadrispherical electrostatic analyzer which is capable of determining the incident plasma distribution parameters for ions and electrons. A schematic of the instrument is shown in Fig. 1. The instrument's analyzer section

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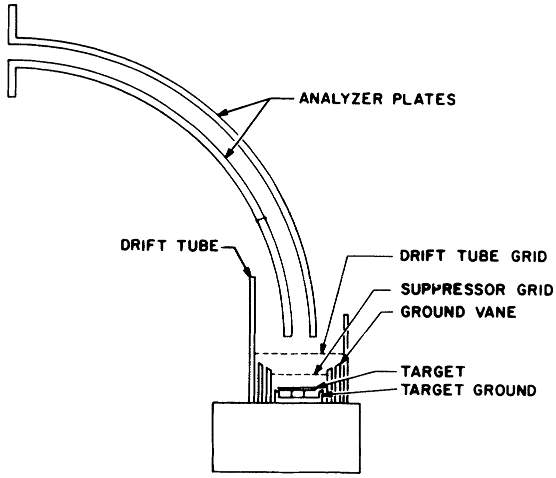

Fig. 1. Central, cross-sectional schematic of the analyzer and detector portions of the Ames Research Center plasma analyzer on the PVO. The instrument is a 90° quadrispherical curved plate electrostatic analyzer with five current collectors and attendant electrometers.

consists of a nested pair of quadrispherical plates with a mean radius of 12 cm and a plate separation of 1.0 cm (see Table I for a summary of instrument characteristics). Charged particles that pass through the entrance aperture, admitting them into the region between the quadrispherical plates, are deflected by an electrostatic field between the plates. Those particles whose E/Q are within a range defined by the electrostatic field strength follow a curved path between the plates and exit from the region between the plates. They are then collected by an array of five flat current collectors located beyond the exit aperture. Each collector is connected to an electrometer amplifier.

By varying the voltage difference between the plates, and hence the electrostatic field strength, a range of E/Q values is covered for both positive ions and electrons. By covering a sufficiently large range of E/Q values, the complete particle spectrum is then measured. The incident direction of the incoming particles is determined from the spacecraft azimuthal angle and the relative responses of the five collectors. The instrument is mounted on the PVO near the outer edge of the spacecraft equipment shelf so that it looks out in a direction parallel to a radius vector from the spacecraft spin axis. The view angle is 140° in a plane parallel to the spin axis and 15° in the plane normal to the spin axis. As indicated in Fig. 2 the multiple collectors enable the instrument to obtain a polar (north-south) angular scan. The spinning of the spacecraft enables the instrument to obtain an azimuthal (longitudinal) angular scan. Thus the experiment is able to directly measure the three dimensional solar wind parameters. As indicated in Table I the range of E/Q values for high energy positive ions is from 50 to 8000 V covered in 32 steps spaced logarithmically equal. For electrons and low energy positive ions the E/Q range from 3 to 250 V is used, covered in 15 logarithmical steps plus a "zero" step at 0.25 V.

B. Description of the Instrument Modes

The instrument has two commandable logic modes of operation: the scan mode and the step mode. In the scan mode, the instrument first performs a maximum flux scan during which the value of the maximum flux, the collector number which observed the maximum flux, and the spacecraft azimuthal angle for the flux are determined for each E/Q step of the selected energy range. Then a polar scan and an azimuthal scan are accomplished at the four consecutive E/Q steps beginning with the step before the one in which the peak flux was measured in the maximum flux scan. A polar scan consists of the maximum flux and corresponding angular sector for all 5 collectors at a given E/Q step. The azimuthal scan contains the flux measured in 12 azimuthal sectors centered on the peak flux direction for the collector which measured the peak flux in the polar scan. The angular sectors are 1/512 of a spacecraft revolution in width. The polar scan and azimuthal scan are accomplished consecutively at each E/Q step. In the step mode the energy is stepped approximately once per second. In the step mode only the maximum flux scan is done. The instrument can be operated with any combination of modes and energy ranges by means of ground command. A complete experiment cycle in either the scan mode or the step mode is stored in a solid state memory chip, thereby separating the instrument sampling time for an energy spectrum from dependence on the spacecraft telemetry bit rate.

TABLE I
INSTRUMENT CHARACTERISTICS

Energy Range			
High Energy Ion	50 - 8000 ev		
Low Energy Electron	0 - 250 ev		
Low Energy Ion	0 - 250 ev		
Energy Steps			
High Energy Ion	32 steps		
Low Energy Electron	16 steps		
Low Energy Ion	16 steps		
Energy Step ΔE/E			
High Energy Range	16.37%		
Low Energy Range	31.59%		
Analyzer System			
Plate Mean Radius	12 cm		
Plate Separation	1.0 cm		
Analyzer Constant	6		
Number of Collectors	5		
Aperture	1.0 cm dia.		
Location	Spacecraft Experiment Compartment		
Field of View		Azimuthal	Polar
Three Central Collectors (ea) No. 2, 3, 4		15°	15°
Two Outer Collectors (ea) No. 1 and 5		15°	47°
Total of 5 collectors		15°	140°
Angular Scan Coverage due to Spacecraft Rotation		360°	140°
Angular Resolution	≤ ± 0.5° (both components)		
Speed Resolution	≤ 1 km/sec		
Density Resolution	≤ 5%		
Temperature Resolution	Dependent on Solar Wind Speed and Density		

C. Description of the Instrument Data Rates and Formats

The actual rate of data generation is a function of operating mode and spin rate. Data readout rates are a function of telemetry format and bit rates. Table II summarizes the data generation rates resulting from the previous discussion of

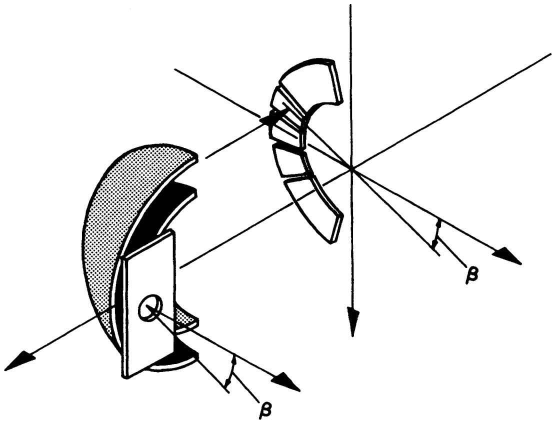

Fig. 2. Solar wind ion analyzer. Schematic of instrument field of view showing circular entrance aperture, curved plates, and array of five current collectors located beyond exit aperture.

TABLE II
INSTRUMENT DATA GENERATION RATES

Mode	Energy Range	Data Bits Inc. Sync Status & Spare	Scan Period				Data Generation Rate	
			Revs		Seconds			
			6 RPM	15 RPM	5 RPM	15 RPM	5 RPM	15 RPM
Scan (M_1)	E_1	1552 bits	45.00	45.00	540 sec	180 sec	2.87 bits/sec	8.62 bits/sec
	E_4 (limit on)	1384 bits	36.00	36.00	432 sec	144 sec	3.20 bits/sec	9.61 bits/sec
	E_2,E_3	1216 bits	27.00	27.00	324 sec	108 sec	3.75 bits/sec	11.3 bits/sec
Step (M_2)	E_1	704 bits	3.08	9.25	73 sec	37 sec	19.00 bits/sec	19.00 bits/sec
	E_4 (limit on)	536 bits	2.42	7.25	29 sec	29 sec	18.5 bits/sec	18.5 bits/sec
	E_2,E_3	368 bits	2.17	6.50	26 sec	26 sec	14.2 bits/sec	14.2 bits/sec

TABLE III
AVAILABLE TELEMETRY RATES FOR THE PLASMA ANALYZER

Spacecraft Bit Rate (bits/sec) (Test format)	Formats			
	Periapsis B at 2 words per minor frame	Apoapsis A, Periapsis A&C and Launch/Cruise at 3 words per minor frame	Apoapsis B at 12 words per minor frame	Playback at 5 words per minor frame
2048	64 bits/sec	96 bits/sec	384 bits/sec	160 bits/sec
1024	32 bits/sec	48 bits/sec	192 bits/sec	80 bits/sec
682-2/3	21-1/3 bits/sec	32 bits/sec	128 bits/sec	53-1/3 bits/sec
512	16 bits/sec	24 bits/sec	96 bits/sec	40 bits/sec
341-1/3	10-2/3 bits/sec	16 bits/sec	64 bits/sec	26-2/3 bits/sec
256	8 bits/sec	12 bits/sec	48 bits/sec	20 bits/sec
170-2/3	5-1/3 bits/sec	8 bits/sec	32 bits/sec	13-1/3 bits/sec
128	4 bits/sec	6 bits/sec	24 bits/sec	10 bits/sec
64	2 bits/sec	3 bits/sec	12 bits/sec	5 bits/sec
16	1/2 bit/sec	3/4 bit/sec	3 bits/sec	1-1/4 bits/sec
8	1/4 bit/sec	3/8 bit/sec	1-1/2 bits/sec	5/8 bits/sec

modes and sequences, using a nominal 5 rev/min for orbiting Venus and using a nominal 15 rev/min for interplanetary cruise. In Table II the scan mode is referred to as M_1 and the step mode as M_2. In Table II the energy ranges are denoted as follows: E_1 is the 32 step range for ions; E_2 is the 15 step range for electrons; E_3 is the 15 step range for low-energy ions, and E_4 is similar to E_1 but the highest energy ranges are not covered (i.e., the high voltage limit is on).

The assigned telemetry words for each format are shown in Table III along with the resultant available data rate. Note that for periapsis format D and E the plasma analyzer is assigned no telemetry space.

III. INSTRUMENT CALIBRATION

Prior to launch, the PVO plasma analyzer experiment was calibrated in the Plasma Ion Calibration Facility at NASA Ames Research Center. This thorough prelaunch calibration of the instrument enables us to obtain absolute solar wind parameters from the plasma analyzer experiment. The prelaunch calibrations are utilized in an iterative least squares fit to the flight data for a variety of possible distribution models in order to determine the plasma ion distribution parameters.

IV. PLASMA ANALYZER RESULTS

The PVO plasma analyzer has operated flawlessly since launch. Several papers have already been written [2]-[5] on a number of issues related to the planetary and interplanetary science objectives of the experiment. In this section of this paper we will discuss a few of the specific scientific results of the PVO plasma analyzer that are indicative of some of the aspects of the instrument's capability.

A. *Ion Observations of the Dayside Interaction*

Initial results of observations of the solar wind interaction with Venus by this experiment indicate that Venus has a well-defined, strong, standing bow shock wave. Across the shock an ionosheath is observed in which the compressed and heated post shocked plasma evidently interacts directly with the Venus ionosphere. The plasma ion velocity deflections observed within the ionosheath are consistent with flow around

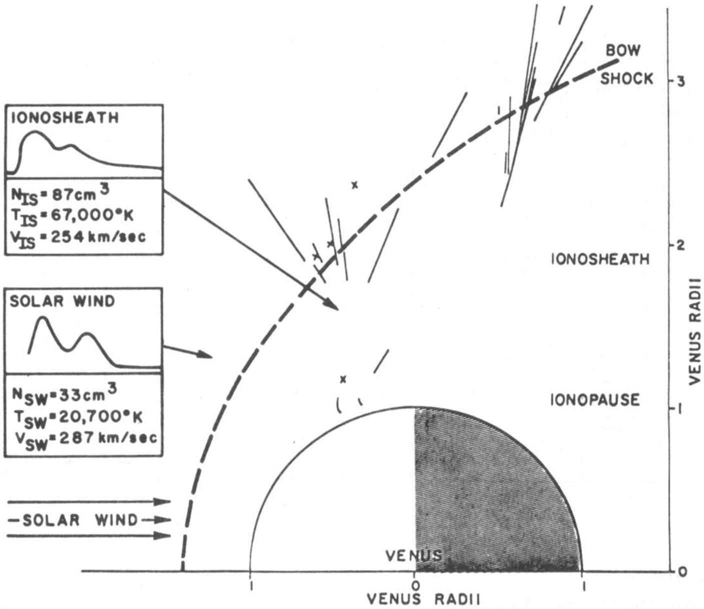

Fig. 3. PVO plasma analyzer bow shock, and ionopause locations (or limits) plotted on a common plane, derived from available data from the plasma analyzer for the first 29 orbits. The two insets show the comparison of a solar wind ion spectrum and an ionosheath ion spectrum from the outbound portion of orbit 6 which were obtained in the vicinity of the terminator (the arrows in the figure, therefore, are only for illustrative purposes indicating that the solar wind is located upstream of the bow shock and that the ionosheath is located behind the bow shock). Some of the parameters derived from a Maxwellian fit to the respective spectra are also shown.

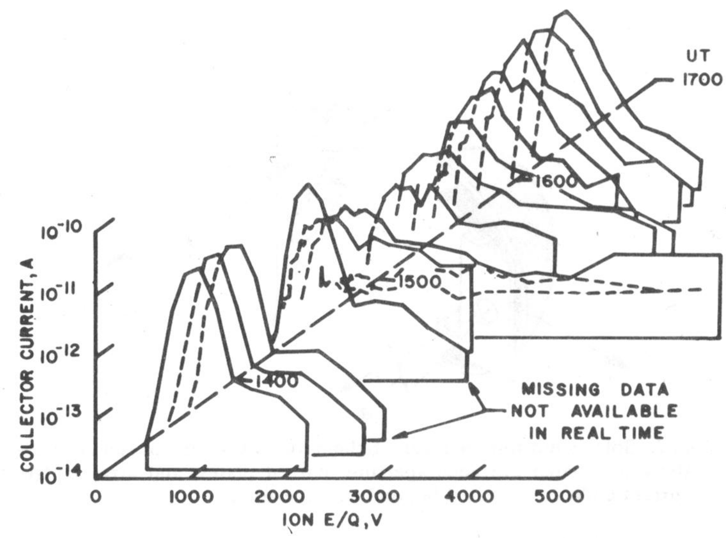

Fig. 4. Successive ion spectra for a portion of orbit 3 centered around periapsis, showing the change in spectral characteristics as the spacecraft passes from the interplanetary medium across the Venus bow shock, through the ionosheath, across the ionopause, and back across these same plasma regimes on the outbound leg.

the blunt shape of the ionopause. The ionopause boundary is observed and defined by this experiment as the location where the ionosheath ion flow is first excluded.

The positions of the bow shock and ionopause are variable and appear to respond to changes in the external solar wind pressure. Fig. 3 shows the bow shock and ionopause locations rotated into a common plane. These locations were observed on the first 29 PVO orbits and are based on real-time data only and on preliminary spacecraft trajectory information. Some possible bow shocks are indicated with extended limits or are omitted and many ionopause crossings are missing because of gaps in the real-time data.

The insets in Fig. 3 show an interplanetary solar wind spectrum and an ionosheath spectrum obtained during relatively quiet conditions. These data were taken on Day 344 (December 10, 1978) in the vicinity of the terminator during the outbound trajectory of orbit 6. For the solar wind spectrum (obtained at 1605:39 UT–spacecraft time) the H^+ peak is at ~400 V and the He^{2+} peak at 800 V. Using the prelaunch calibration results in a least squares Maxwellian fit to the data the plasma parameters derived from this spectrum are obtained. Some of these parameters (e.g., N, the proton number density; T, the isotropic proton temperature; and V, the bulk speed of the protons) are also indicated in the inset. For this case the components of the solar wind flow direction were +4.2° in azimuthal angle (from the west when facing the solar direction) and +0.5° in polar angle (from the north) measured perpendicular to the Venus orbital plane. The ionosheath spectrum with its corresponding parameters are shown and the flow directions for this spectrum are an azimuthal angle of +6.5° and a polar angle of +17.4°.

Fig. 4 shows a sequence of E/Q spectra around periapsis on orbit 3. The first four spectra were obtained in the free stream solar wind upstream of the bow shock. The next two were obtained downstream of the bow shock in the Venus ionosheath. Both the lower levels of the peak currents associated with these spectra and the increased widths indicate thermalization of solar wind ions across the bow shock and conversions of streaming energy into particle heating. The two spectra with depressed current levels (at 1435 and 1443 UT) indicate the absence of measurable plasma ion flux in this energy range in the ionosphere below the ionopause. The subsequent spectra were obtained during the outbound portion of the orbit: they indicate the recrossing of the ionopause and finally, after 1536 UT, the reemergence of the spacecraft into the free stream solar wind.

B. Low-Energy Ion Observation in the Ionosphere

Observations in the ionosphere near periapsis were obtained by the plasma analyzer in its low-energy ion mode. Fig. 5 shows the low-energy ion spectrum obtained between 0 and 40 V at ~1500 UT on December 11, during orbit 7 when the spacecraft was at an altitude of ~310 km. The first peak in the spectrum occurs at ~8 V and the maximum of the broader second peak occurs at ~15 V. Because of the measured angle of incidence, we interpret these data as indicating nonflowing ions apparently impinging from a direction along the ram velocity vector of the spacecraft. The ram speed at this time was ~9.7 km/s so that the peak in the spectrum at ~8 V is consistent with an ion of mass 16, such as O^+, as indicated by the arrow in Fig. 5. Several ions could give rise to the second peak, and the mass positions of CO^+, O_2^+, and CO_2^+ ions expected at this altitude in the Venus ionosphere are shown in Fig. 5.

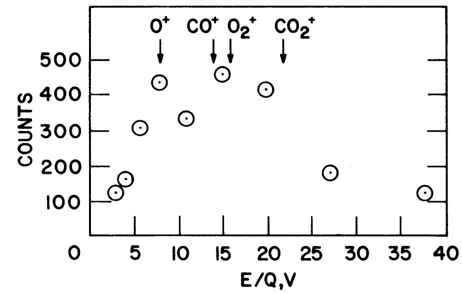

Fig. 5. Typical low-energy ion spectrum obtained in the ionosphere near periapsis on orbit 7. This spectrum is interpreted as representing nonflowing ionospheric ions incident from the ram direction and is consistent with ion species expected in the Venus ionosphere.

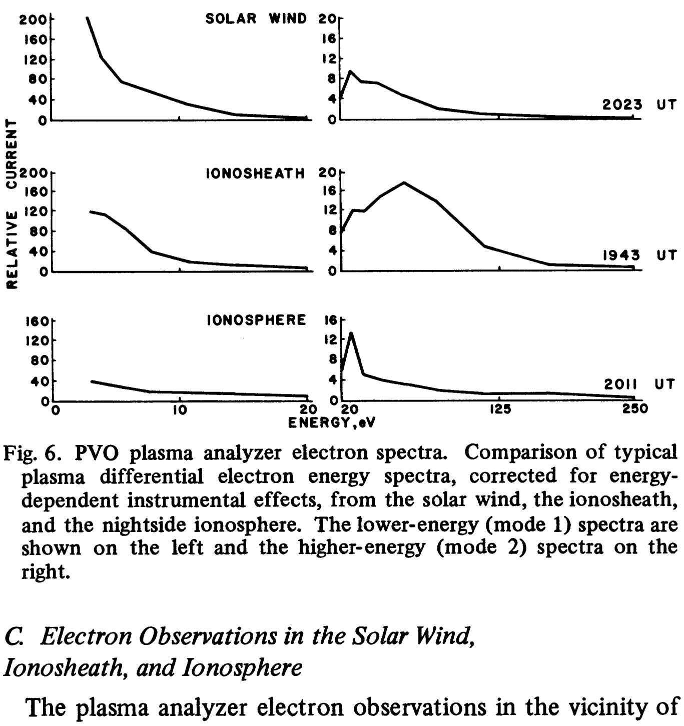

Fig. 6. PVO plasma analyzer electron spectra. Comparison of typical plasma differential electron energy spectra, corrected for energy-dependent instrumental effects, from the solar wind, the ionosheath, and the nightside ionosphere. The lower-energy (mode 1) spectra are shown on the left and the higher-energy (mode 2) spectra on the right.

C. Electron Observations in the Solar Wind, Ionosheath, and Ionosphere

The plasma analyzer electron observations in the vicinity of Venus indicate that there are three distinct plasma electron populations—solar wind electrons, ionosheath electrons, and nightside ionosphere electrons. Fig. 6 shows an example of each of these electron populations. All energy dependent correlations have been made so Fig. 6 shows a measured relative differential electron current as a function of energy, measured in two instrument modes, covering two adjacent energy ranges, running from nearly 0 to 250 eV. The top panels in Fig. 6 show a typical solar wind electron spectrum. The middle panels, a typical ionosheath spectrum, show a broader peak in the higher energies, most likely associated with thermal heating of solar wind electrons across the Venus bow shock. The peak at lowest energies, on the left in both the solar wind and the ionosheath spectra, is identified as primarily associated with photoelectrons from the spacecraft. The bottom panels show a typical nightside ionosphere electron spectrum, recorded in the optical shadow of Venus and lacking a low-energy peak, consistent with the association of the low-energy peak with spacecraft photoelectrons.

These and our other [3] plasma electron observations show possibly enhanced current levels in the nightside ionosphere. These may be associated with physical processes connected with the maintenance and energetics of the nightside ionosphere, the location of the nightside ionopause, and the other nightside ionospheric phenomena.

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