Scientific Results from the Pioneer 11 Mission to Jupiter

The first direct measurements of the environment of Jupiter were made in 1973 from the spacecraft Pioneer 10. The results of the Pioneer 10 encounter have been reported here (*1*) and elsewhere in the scientific literature (*2*). Pioneer 10 was followed by its sister spacecraft, Pioneer 11, which reached Jupiter in November–December 1974. The initial results from this second encounter are presented in the following reports by the Pioneer investigators.

Hall (*3*) has described the spacecraft and mission in the preceding report of this series. The encounter geometry of Pioneer 10 was selected to carry the spacecraft on a near-equatorial trajectory past Jupiter. Pioneer 10 reached a point of closest approach of 2.8 Joviocentric radii (R_J) (1 $R_J =$ 71,372 km). Pioneer 11 approached the planet from 50° south of the equator, reached its point of closest approach at 1.59 R_J, and exited at a high northern latitude, thereby complementing the Pioneer 10 trajectory by exploring a large range of latitudes and longitudes.

Magnetosphere, magnetic field, and radiation belts. The presence of a detached bow shock wave and magnetosphere at Jupiter was established by Pioneer 10. Pioneer 10 recorded the first bow shock crossing at 108.9 R_J and the magnetospheric boundary at 96.4 R_J. Based on the Pioneer 10 energetic particle results, several investigators had postulated a relatively flat, disklike magnetosphere, modulated on a 10-hour period by the rotational period of the planet. Pioneer 11 entered the magnetosphere near the equator and exited at about 30° northward of the nose. On the inbound pass Pioneer 11 detected the bow shock at 109.7 R_J and the magnetospheric boundary at 97 R_J. On the outbound trajectory Pioneer 11 recorded its final crossing of the magnetospheric boundary at 80 R_J. The detection of the magnetospheric boundary at a relatively high latitude (30°) and at 80 R_J, coupled with the fact that the spacecraft crossed the magnetosheath several times argues for a large (greater than 80 R_J) blunt magnetosphere. During the high-latitude outbound passage of Pioneer 11 the high-energy electrons and protons were detected with intensities as great as those found in the equatorial region. One can conclude from this either that a relatively thin magnetodisk model does not describe the particle distribution or that the magnetodisk is only one of the mechanisms governing the distribution of particles in the outer magnetosphere.

From approximately 65 R_J inward to near 25 R_J a transition radiation belt was observed in which the energetic particles were observed to be corotating with the magnetic field but not in trapped orbits, which completely circle the planet. Within 25 R_J the same stable trapping zone was observed as on Pioneer 10. Pioneer 10 instruments observed a maximum in the proton intensity near 3.4 R_J. Pioneer 11 instruments observed this same maximum, but, in addition, the instrumentation also measured a series of peaks in the proton flux inside 3.4 R_J. A flux of approximately 10^7 proton cm^{-2} sec^{-1} was observed at 1.9 R_J. This is about 20 times the intensity observed at 3.4 R_J. The flux of electrons with relativistic energy reached a maximum at 1.8 R_J. The maximum is, however, only slightly different from the Pioneer 10 peak observed at 3.1 R_J 1 year earlier, thus indicating a stable electron distribution in time and space inside 3.1 R_J. The flux of electrons at high latitudes measured by the Pioneer 11 instruments was significantly higher than would have been estimated from the Pioneer 10 magnetodisk model. This is further evidence that the disk model is inadequate as a description of the Jovian magnetosphere.

Much of the structure in the proton distribution inside 3 R_J has been attributed to a sweeping effect by Amalthea. A large spike and then a dropout of protons was also observed on the magnetic L shell passing through Io. In the 0.5- to 3.41-Mev range, the proton flux dropped by a factor of 100. The 40- to 500-kev electron flux dropped by a factor of 10, whereas the 20- to 30-Mev electron flux was largely unaffected. No substantial effect was found associated with Europa; however, a burst structure was found near Ganymede, indicative of some type of acceleration on the L shell of Ganymede.

The structure of the magnetic field has also been proposed as an explanation for the peaked nature of the inner radiation belt. Pioneer 10 observations supported the idea of an offset tilted dipole with some higher-order pole terms. Pioneer 11 observed closer to the planet and transited the planet in a retrograde trajectory. It observed the rotation of Jupiter through 720° of longitude. These new data have enabled the Pioneer investigators to develop a field model based on an internal dipole, quadrupole, and possibly octopole and an external dipole and quadrupole. This field can explain some of the fine structure found in the particle distribution in the inner radiation belt (*4*).

The planet and atmosphere. The thermal radiation from Jupiter has been a persistent planetary problem which has defied solution for many years. Ground-based observations have indicated that the planet is radiating back into space approximately twice as much heat as it receives from the Sun. Because of Jupiter's great outward distance from Earth, neither the dawn nor dusk terminators can be observed by ground-based telescopes. Consequently, the Pioneer 10 and Pioneer 11 missions had as one of their objectives to observe the thermal radiation at the terminator and dark hemisphere of Jupiter. The Pioneer 10 infrared radiometer investigators derived a net energy output of 2.0 to 2.5 times the input. The observation was repeated on Pioneer 11, and a value of 1.9 times the input was determined. The investigators do not feel that this slightly lower value can be explained by latitudinal or temporal variations on Jupiter; it probably represents a difference in instrument calibration.

An effective temperature of 125° ± 2°K was observed by the infrared radiometers. This also is somewhat lower than the effective temperature of 134° ± 4°K determined by ground-based observations. A temperature of 400°K was determined from the radio occultation data for the 500-mbar level. At 500 mbar Pioneer infrared and ground-based observations derived a temperature of about 130°K. Two explanations have been put forward for the disagreement between the infrared temperature and the radio occultation temperature. In the first it is proposed that a layer of small particulate matter is present at the 1- to 10-mbar level which is biasing the infrared data. This explanation is difficult to reconcile with ground-based determinations of the atmospheric composition and the 130°K temperature determined by microwave observations, which would not be affected by such a dust layer.

The second explanation is that some form of refraction or multipath propagation through the Jovian atmosphere is occurring, which is introducing errors into the radio propagation results. The occultation experimenters are presently investigating the validity of this second explanation.

The imaging photopolarimeter has taken pictures of the planet, both from equatorial and high latitude locations. The Pioneer 11 images are the first polar images of Jupiter ever recorded. They show a decrease in the banding structure of the planet with increased latitude and a more mottled structure across the poles.

Postencounter. Pioneer 11 passed Jupiter on a retrograde encounter trajectory. After encounter the spacecraft swung onto a path to intercept Saturn in September 1979. At the present time all instruments are functioning properly, and they give every indication of surviving until the Saturn encounter.

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References

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Pioneer 11 Encounter: Preliminary Results from the Ames Research Center Plasma Analyzer Experiment

Abstract. *Pioneer 11 observations of the interaction of Jupiter's magnetosphere with the distant solar wind have confirmed the earlier Pioneer 10 observations of the great size and extreme variability of the outer magnetosphere. The nature of the plasma transitions across Jupiter's bow shock and magnetopause as observed on Pioneer 10 have also been confirmed on Pioneer 11. However, the northward direction of the Pioneer 11 outbound trajectory and the distance of the final magnetopause crossing (80 Jupiter radii) now suggest that Jupiter's magnetosphere is extremely broad with a half-thickness (normal to the ecliptic plane in the noon meridian) which is comparable to or greater than the sunward distance to the nose.*

The Pioneer 11 spacecraft, launched on 6 April 1973, passed by Jupiter at a distance of 113,850 km from the center of the planet at 0522 on 3 December 1974. (The times in this report are U.T. and refer to the spacecraft location.) As in the case of Pioneer 10, which a year earlier was the first spacecraft to explore the Jovian environment (*1*), the Pioneer 11 payload included a plasma analyzer experiment to measure properties of the interplanetary plasma (solar wind) from Earth's orbit to beyond the orbit of Jupiter, as well as the interaction with Jupiter's magnetosphere. The Pioneer 11 Ames Research Center plasma analyzer experiment is identical to that on Pioneer 10 and uses two separate quadrispherical 90° electrostatic analyzers for energy and angular analysis (*2, 3*). A medium-resolution analyzer uses five separate current collectors with associated electrometer tube amplifiers as detectors; a high-resolution analyzer uses 26 Bendix Channeltron electron multipliers as detectors. Both the Pioneer 10 and the Pioneer 11 spacecrafts are spin-stabilized, with the spin axis oriented so that the spacecraft high-gain communications antenna is directed earthward. The entrance apertures for both electrostatic analyzers in the plasma experiment are directed along the spacecraft spin axis. Consequently the spacecraft spin, or roll (5.0 rev min^{-1} during Pioneer 11 encounter), makes possible plasma flux measurements at various azimuthal angles of the spacecraft spin, whereas the multiple detectors just described make possible, at any spacecraft roll angle, plasma flux measurements at various polar angles with respect to the spacecraft spin axis. The complete experiment covers a proton energy range of 100 to 18,000 ev and an electron energy range of approximately 1 to 500 ev.

Pioneer 11 approached Jupiter in the morning quadrant at an angle with respect to the solar direction slightly greater than 40°, similar to the case of Pioneer 10. The encounter trajectory of Pioneer 11 is given in Fig. 1, both projected onto Jupiter's equatorial plane and as an orthogonal projection on a plane that contains the direction to the Sun. As seen in Fig. 1, the Pioneer 11 outbound trajectory, which permits encounter with the planet Saturn in early September 1979, was toward the solar direction and northward.

As in the case of Pioneer 10 (*3*), bow stock and magnetopause boundaries were identified in the Pioneer 11 plasma experiment data during Jupiter encounter, forming an analogy with the case of Earth's interaction with the solar wind (*4*). The bow shock, at which the flow Mach number drops below unity, is a standing discontinuity in the solar wind upstream from the magnetopause. The magnetopause forms the boundary between the shocked solar plasma (magnetosheath) and the planetary magnetic field (magnetosphere) around which the solar wind plasma is deflected. The multiple observations of Jupiter's bow shock and magnetopause are accounted for as a result of motion of these surfaces toward and away from Jupiter, past the spacecraft, in response to changing solar wind dynamic pressure.

The inward bow shock crossings are signaled by an abrupt decrease in the solar wind bulk speed accompanied by a flow deflection on the order of 30° or more, a proton number density increase, and a large proton temperature increase. The first Pioneer 11 Jupiter bow shock crossing was observed at 0339 on 26 November 1974 at a planet-centered distance of 109.7 R_J (R_J = Jupiter radius, taken to be 71,372 km). At this time the solar wind bulk speed (spacecraft frame of reference) decreased from 480 to 328 km sec^{-1} with a concurrent shift of the flow direction of approximately 50° and a proton isotropic temperature increase from about 2×10^4 to 5×10^5 K. The transition time for the proton bulk speed is longer than 10 minutes in this case. The time for proton bulk speed changes at these shock crossings generally seems to be longer than the times for the flow direction and temperature changes. The proton number density increased by at least a factor of 2.5 across the shock transition from an upstream value of 0.06 cm^{-3}. More precise values of the density jump across the inbound shock crossings are not yet available in the preliminary data because correction factors still have to be applied to account for the large