NASA Facts
An Educational Publication
of the
National Aeronautics and
Space Administration

NF-89

The Voyager Mission

Jupiter, The Giant of the Solar System

In orbit 780 million km (485 million mi) from the Sun, Jupiter is four-and-a-half times as distant from the Sun as is the Earth. The planet is unusual by earthly standards; it is only slightly denser than water, but 318 times more massive than the Earth. Because of this great mass, which is more than that of all the other planets combined, Jupiter dominates the Solar System after the Sun. Its powerful gravity pulls the orbits of the other planets out of shape, and may have prevented the asteroids from forming a planet. The orbits of comets are also affected by Jupiter; some comets have even been captured by the big planet and are under its control.

The giant Jupiter differs greatly from Earth and the terrestrial rocky planets, Mercury, Venus, and Mars, in that Jupiter does not appear to have any solid surface, but is a great ball of liquid topped by a thin shell of gas. It consists mainly of hydrogen, with a small quantity of helium and traces of ammonia, methane, water, ethane, and acetylene. The interior of the planet is believed to change gradually with depth from a gaseous mixture of hydrogen and helium—about one atom of helium for every ten molecules of hydrogen—to an interior of liquid metallic hydrogen. There may also be a small rocky core.

After the Sun, Jupiter is also the noisiest source of radio signals in the solar system. The radiation we receive at Earth from Jupiter consists of three types. Thermal radio waves are produced by molecules moving about in the atmosphere of the giant planet. Radio waves in the decameter range are produced by electrical discharges in the atmosphere and are somehow influenced by the movement of one of the satellites, Io, along its orbit. Radio waves in the decimeter range are produced by electrons in the magnetosphere of Jupiter. It was these decimetric waves that led scientists to conclude that Jupiter has a magnetic field like that of the Earth because the particles responsible for generating them must be trapped in such a field. This magnetic field and magnetosphere of Jupiter was confirmed by NASA's Pioneer spacecraft flying by the planet in 1973 and 1974.

The visible surface of Jupiter is the top of turbulent clouds. Estimates of the depth of the atmosphere beneath these clouds vary from 100 to 5800 km (60 to 3600 mi). Below the atmospheric shell is a deep ocean of liquid hydrogen. Astronomers agree generally about the internal structure of Jupiter (Figure 1), but they differ about the details. At the high pressure deep within the planet, hydrogen becomes metallic in form and readily conducts heat and electricity. There is a shell of this liquid metallic hydrogen surrounding a rocky core, which also probably contains heavier

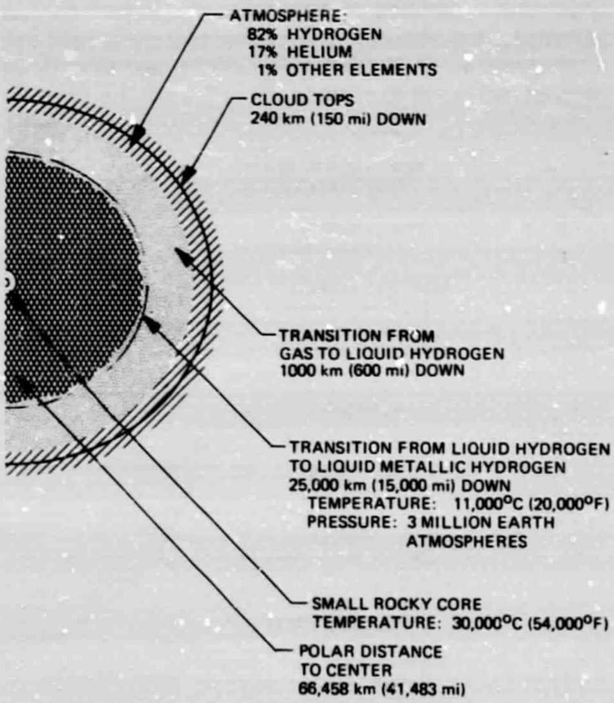

Figure 1. Diagram of the interior of the planet Jupiter according to a commonly accepted model.

(NASA-TM-79953) NASA FACTS: AN EDUCATIONAL PUBLICATION OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION. THE VOYAGER MISSION (National Aeronautics and Space Administration) 8 p MF A01; SOD HC CSCL 03B G3/91
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metals. The helium of the planet might be mixed with the hydrogen in solution, or might have condensed into a shell of liquid helium surrounding the core. At the core, temperatures might be as high as 30,000°C (54,000°F). Such a hot core could account for Jupiter radiating into space some two-and-a-half times as much heat as it receives from the Sun.

At one time astronomers thought that Jupiter generates heat by the pressure of its own gravity compressing its interior and causing it to contract in size. Now some astronomers favor the explanation that Jupiter is hot today because it is still cooling down from its formation. As it cools it continues to contract. Jupiter is too small for the weight of its massive bulk to compress the material at its center sufficiently to ignite nuclear reactions there. Had Jupiter been larger it might have formed a second sun, so that the Solar System would have become a binary star system.

Origin of Jupiter

Scientists think that the cloud of gas from which Jupiter was formed gave birth to the giant planet about 4½ billion years ago by a 70,000-year convulsive contraction that was followed by a headlong collapse to form the planet in a brief three months. The initial cloud from which Jupiter originated was probably 650-million km (400-million mi) in diameter, but within the 70,000 years of initial formation it rapidly shrank and heated from a temperature of −218°C (−360°F) to 2200°C (4000°F). The hydrogen molecules ionized and broke up, and the protoplanet collapsed within a few months to about five times its present diameter. As it did, enormous quantities of heat were developed by the tremendous pressures. The interior of Jupiter reached a temperature of 50,000°C (90,000°F), and the planet glowed red hot at its surface. Over the billions of years to the present, the planet has gradually cooled. Evidence for this red-hot phase is thought to be the decreasing density of the big satellites of Jupiter with increasing distance from the planet. The innermost moons were heated so much by the hot planet that most lightweight substances (volatiles) were driven into space. Water was prevented from condensing or remaining in any substantial quantities on them.

Jupiter as Seen from Earth

Jupiter completes an orbit about the Sun in 11.86 years. When Jupiter appears opposite to the Sun as seen from Earth, astronomers say that the planet is in opposition. At this time the planet is closest to the Earth and shines its brightest in the night sky, directly south at midnight. During NASA's Voyager mission to Jupiter, oppositions of the planet will occur during the winter months—December 1977 in the constellation of Taurus, January 1979 in Gemini, and February 1980 in Cancer. Even small telescopes will reveal bands of clouds and show the four big satellites as star-like objects moving in their orbits about Jupiter.

Jupiter completes a rotation on its axis in 9 h, 55 min, and 30 s. This rapid rotation has flattened the poles and bulged the equator of Jupiter. The polar and equatorial diameters are 133,516 km and 142,796 km (82,966 mi and 88,734 mi) respectively. Seen by telescope from Earth, Jupiter appears as a striped, banded disc (Figure 2), with all the markings parallel to the equator. Dusky-gray regions cover each pole. The dark, slate-gray stripes are called belts. They are believed to be regions of descending air masses. The lighter, salmon-colored bands, called zones, are believed to be rising cloudy air masses. A transparent atmosphere extends high above the visible cloud tops of the belts and zones.

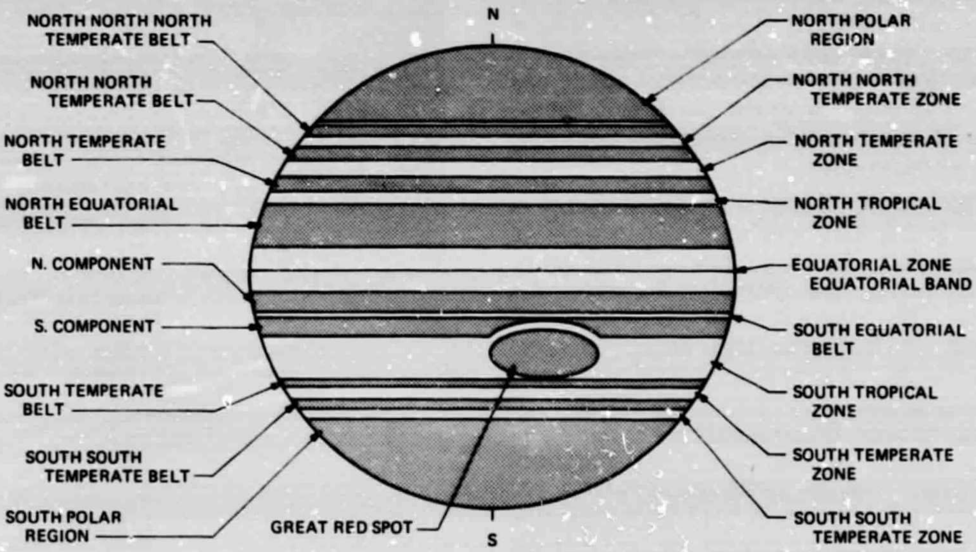

Figure 2. The visible surface of Jupiter consists of a banded structure of clouds that are consistent enough to have been given the names shown in this drawing.

Among the belts and zones are many smaller features—streaks, wisps, arches, plumes, and spots—some of which may be knots of clouds. They change form rapidly even though they are thousands of kilometers in size. This indicates a very turbulent atmosphere.

The cloud features move around Jupiter more slowly at increasing distance from the equator. A great equatorial current sweeps around the planet some 400 km/h (250 mi/hr) faster than the regions on either side of it. Telescopic observations show that air masses move parallel to Jupiter's equator rather than from the equator toward the poles, as on Earth. Cloud motions have been measured in the zones that indicate speeds of 320 km/h (200 mi/h) relative to the whole planet.

The bands around Jupiter are explained as convective cells in the atmosphere that are stretched out because of the planet's rapid rotation. At the top of these light zones, the cooler material moves toward the equator and toward the pole and is deflected in an east-west direction by the rotation of the planet before it sinks back to lower altitude in the dark belts. Above 50-deg north and below 50-deg south latitudes, the banded structure ends and the atmosphere is turbulently disorganized into many convective cells (Figure 3).

In the southern hemisphere is a 24,000-km (15,000-mi) diameter oval feature known as the Great Red Spot (Figure 4), which has intrigued astronomers and theorists since it was first observed centuries ago. The spot has varied in intensity, color, and size over the years, and several times it has almost completely disappeared. There are also smaller red spots and white spots within the turbulent cloud systems of Jupiter.

Scientists now think they have discovered some of the main features of Jupiter's atmosphere and weather. The weather probably occurs in a thin skin of the atmosphere as it does on Earth. The bottom of the weather layer is at the base of the lowest clouds of water, below which is a relatively uniformly-heated deep atmosphere of hydrogen and helium. Instead of moving from the equator to the poles and back, as on Earth, Jupiter's weather circulation seems to consist of a relatively local turbulence in the polar regions, and a flow parallel to the equator in the temperate and equatorial regions. This means that weather circulation on the whole planet is somewhat like weather in the Earth's tropical regions.

The heat rising from the interior of Jupiter appears to be shunted away internally from the equatorial regions, which are warmed by incoming solar radiation. The result is that the planet behaves as though controlled by a giant thermostat so that its atmosphere has a temperature at the polar regions similar to that at the equator, and in both day and night hemispheres. If there is, indeed, no flow of heat in the atmosphere from the equator toward the poles, the weather on Jupiter must be driven by the internal heat, not by solar heat as on Earth.

Figure 3. This enlargement of a Pioneer 11 picture covers part of Jupiter's north temperate zone and its north polar region. It shows the breakup of the regular banded structure of Jupiter's clouds northward toward the pole.

Zones are believed to be similar to cyclones on Earth, but on Jupiter they are stretched out around the planet (Figure 5). Heat released from the condensation of water within rising masses of atmosphere called cells could drive the rising cells even higher. More water-laden atmosphere would be sucked into the rising columns and reinforce this effect.

The zones may thus be planet-girdling, cyclone-type features consisting of long strips of rising atmosphere powered endlessly by the condensation of water vapor. There are, however, other explanations for Jupiter's weather systems, such as a slight equator-to-pole heat flow, and the effects of the huge size of the planet on the way fluids flow within it. Also, the liquid interior of Jupiter may affect convective flow in a way that gives rise to zones in the atmosphere of differing heat, which causes them to rise and fall. The NASA Voyager spacecraft will gather new information that should allow scientists to choose between the various current theories. It seems clear, however, that the basic differences between weather of the Earth and of Jupiter arise from the lack of a solid surface on Jupiter and

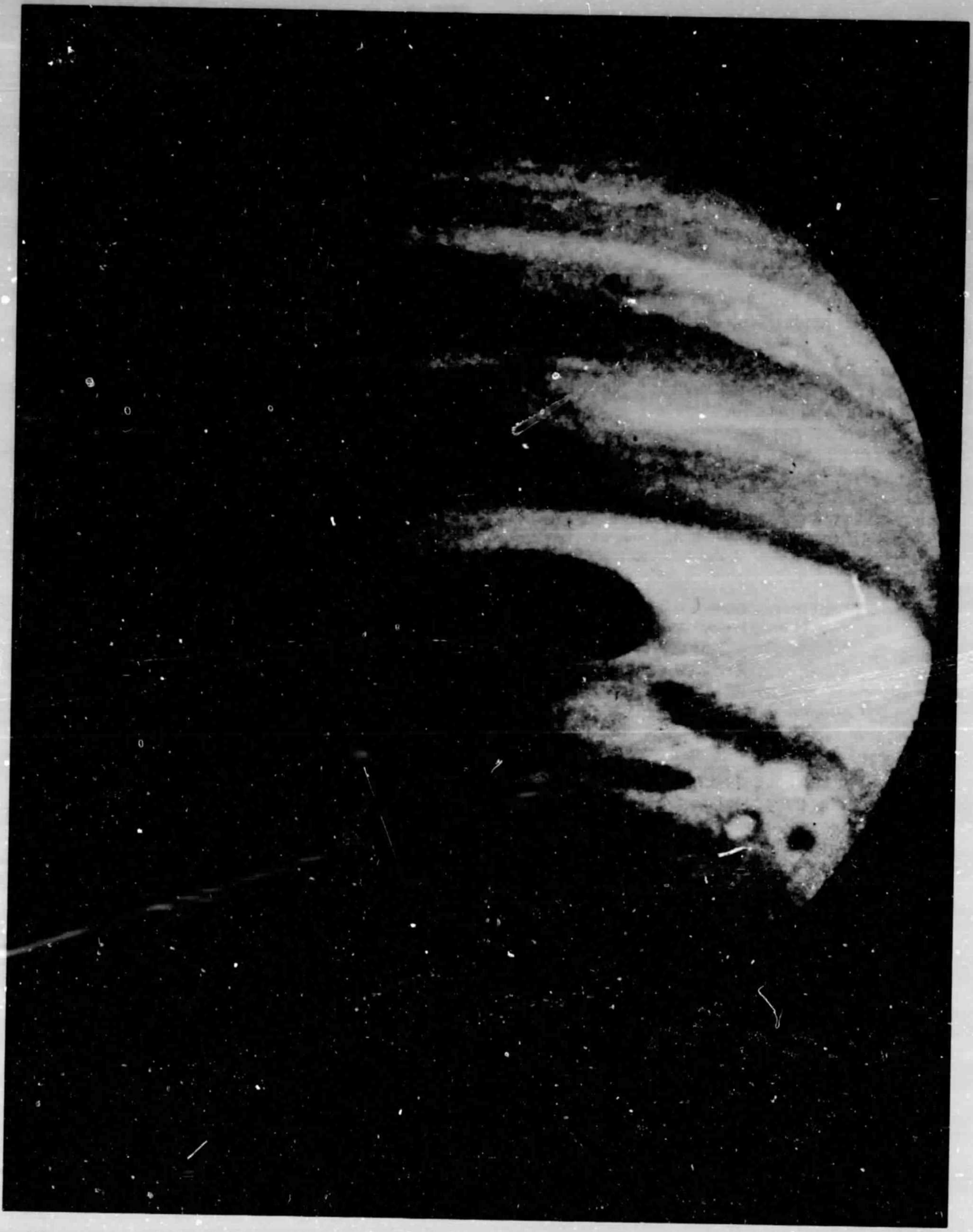

Figure 4. In the southern hemisphere of Jupiter there is a 25,000-km long oval feature called the Great Red Spot, which has been seen on the planet for hundreds of years.

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Figure 5. Convection patterns proposed for flow of Jupiter's liquid interior are shown in this diagram. Near the poles, the circular flow of liquid hydrogen by convection (rising of heated material) is conventional. In the equatorial regions, however, there may be a series of turning convective rolls, parallel to Jupiter's rotation axis. Convective flow would occur in the zone of molecular hydrogen and be unable to cross the boundary into the region of liquid metallic hydrogen. Convective flow in a rapidly rotating liquid sphere is different from that in a static liquid.

from internal heating of the giant planet as opposed to the Earth's heating from the Sun. Clouds and atmospheric features can go unchanged for decades or for centuries on Jupiter because there is very little friction between the thin cloud layers and the compressed atmospheric gas below them. There is no solid surface like that of the Earth to affect the flow of atmospheric gases.

Permanent features seen in the atmosphere, such as the Great Red Spot (Figure 6) could be 'free-wheeling' phenomena that require relatively small inputs of energy to keep them going. Jupiter's hydrogen atmosphere retains energy more easily than does Earth's atmosphere of nitrogen and oxygen. Consequently, once a free-wheeling phenomenon has received energy, a long time can elapse before the energy is dissipated. The Great Red Spot turns like a wheel between the north and south halves of the South Tropical Zone, which is split by the spot. Over the 300 years since it was first observed, the spot has drifted westward at an irregular rate. There are smaller red spots in other zones, but these have not lasted as long as the big spot. The spot has been simulated on computer models by assuming that it is a rising column of gas spun between the halves of the tropical zone in which it is located. Some scientists speculate that this column rises to a height in the atmosphere at which traces of phosphorus can condense and thereby create its deep red color. The top of the red cloud is some 8 km (5 mi) above the surrounding clouds.

Figure 6. The Great Red Spot, seen in close-up by Pioneer 11, displays a mottled appearance within its interior, which may be turbulent cloud systems. Other smaller spots can be seen nearby.

The highest clouds on Jupiter are the deepest colored, and the red color may be due to phosphorus. The next highest clouds are white; believed to be ammonia crystal clouds. Below these are gray or brown clouds that may consist of ammonia and sulfur compounds or complex organic molecules. The water clouds, where water condenses and releases latent heat, may form a transition region between the uniformly mixed lower atmosphere and the upper region of weather. (See Figure 7.)

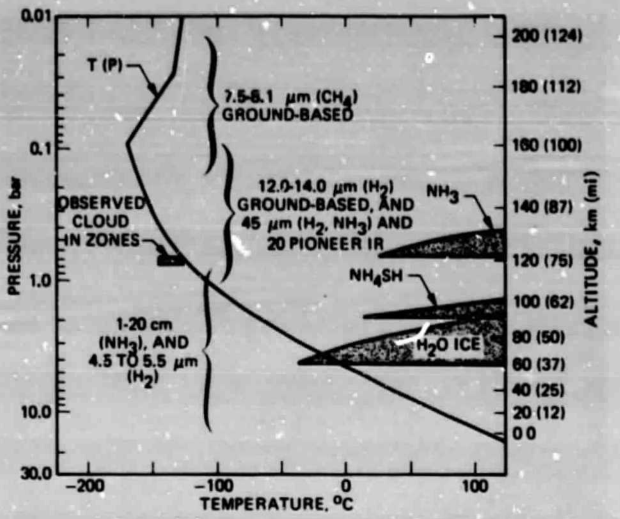

Figure 7. Diagram of the atmosphere of Jupiter showing the position of the main cloud layers and the temperatures and pressures at their levels as calculated by A. Ingersoll of Caltech.

However, we are still quite ignorant of the true nature and origin of the material that makes up the colors of the clouds of Jupiter. The colored material might originate in high temperature chemistry taking place beneath the cloud layers and be swept to high altitudes by the upwelling storm systems. Full-disc color movies of Jupiter will be obtained by the Voyager spacecraft and may show the interactions between cloud motions and color on the planet.

Atmospheric features on Jupiter will be tracked by Voyager's cameras in an attempt to understand the meteorology of Jupiter better. Such understanding will help us also understand the complex terrestrial patterns of weather systems. Voyager will be able to show us how the Jupiter weather features change over a period of time and confirm whether or not they are convective storms like huge hurricanes. The Great Red Spot and other smaller spots may be dynamic meteorological phenomena, i.e., huge storm systems. The mottled appearance within the Great Red Spot as seen in the Pioneer pictures suggests such convective motion. If the Great Red Spot can be photographed at the edge of the planet, we might be able to obtain its profile and find out exactly how high it pokes above the rest of the cloud systems. Differences in color revealed by high magnification imaging may provide us with clues on the composition of the clouds. On the dark side of the planet, we can also look for lightning discharges in an attempt to discover if these are causes of the decametric radio waves.

To explain the Great Red Spot, we need to find out how the smaller red spots form and later fade by looking at them with the high magnification possible with the Voyager cameras. Then we can see all the details of their structure and find out how these details change as the spots evolve. At the same time, instruments carried by the Voyager spacecraft will look at the thermal and other properties of the atmosphere of Jupiter.

The temperature of the upper atmosphere of Jupiter appears to be higher than would be expected from heating by incoming solar radiation and outgoing heat from the planet itself. Some unknown mechanism could be the cause. Possibly there is an interaction between particles in Jupiter's magnetosphere and the gases of the upper atmosphere. The Voyager spacecraft will try to resolve the question by observing ultraviolet radiation from the planet's upper atmosphere. This will provide information about the nature of the processes taking place there.

The Magnetosphere

The magnetosphere of Jupiter (Figure 8) in which protons and electrons are controlled or trapped by the magnetic field of the planet has a volume one million times that of the Earth. Jupiter's magnetosphere is large because relatively low-energy particles spinning off from the top of the ionosphere stretch the magnetic field lines. Outflowing low-energy particles, however, can produce only a very weak magnetic field at great distances from the planet. High-speed gusts of the solar wind periodically push back this weak field and force the magnetosphere to collapse. As it does, energy is imparted to electrons and they are accelerated almost to the speed of light. They squirt across the solar system to Earth and even to Mercury. One of the unexplained effects is that electrons surge out from Jupiter once every ten hours.

The entire magnetosphere of Jupiter behaves like an enormous, fast-rotating, leaky bag, the outer skin of which moves about 2½ times as fast as the 1.6 million km/h (1 million mi/h) solar wind, the blizzard of electrons and protons streaming outward from the Sun. The continuous buffeting and shaking of this huge spinning bag of particles as the magnetosphere of Jupiter rubs and bumps against the pressure of the solar wind, interrupts the regular movement of particles from pole to pole within the magnetic field of Jupiter along the field lines, and throws them inward toward the planet, thereby recirculating and energizing them. The magnetosphere contains radiation belts that are 5000 to 10,000 times as intense as those of Earth. This tremendous intensity may originate from recirculation of particles with increase of their energy each time around.

Particles from the radiation belts around Jupiter move to the turbulent outer magnetosphere along lines connected to the magnetic poles of the planet, which are offset from the rotation poles. There they are redirected by snarled magnetic fields and some of the particles move back to the inner radiation belt. The inward motion increases the energy of these particles. Each time they repeat the cycle they obtain more energy. Although many of the particles are absorbed by the Galilean satellites, some eventually acquire

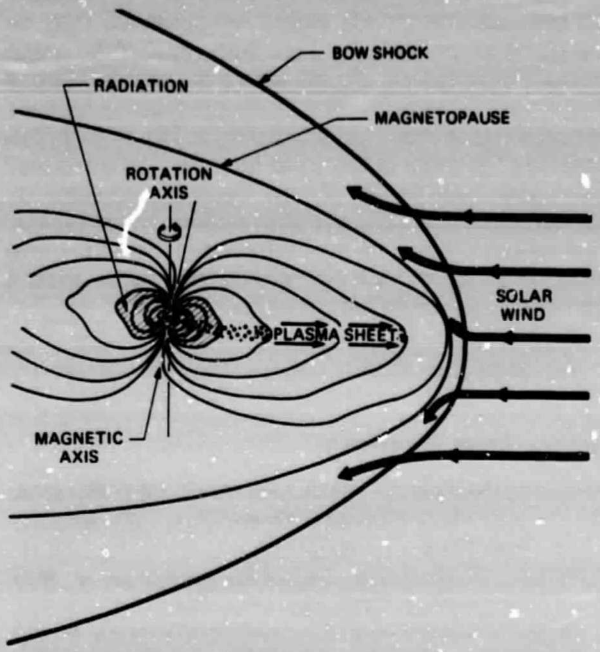

Figure 8. Jupiter's magnetosphere is created by the planet's powerful magnetic field holding ionized particles of the solar wind away from the planet. The magnetic field is at least doubled in size by ionized particles from the top of Jupiter's ionosphere. As these particles are spun out by centrifugal force, they drag the magnetic field with them. Jupiter's magnetosphere has an average diameter of nine million miles, big enough, if it could be seen from Earth, half a billion miles away, to occupy 2 deg of sky, compared to the 0.5 deg occupied by the Sun and the Moon.

enormous energies and squirt out from Jupiter across the Solar System.

The radiation belts of Jupiter would probably be 100 times more intense without the sweeping effects of the Galilean satellites and the squirting of particles into interplanetary space. The particles in the radiation belts probably come from the top of Jupiter's ionosphere rather than from the solar wind. By contrast, Earth's radiation belts are made up of particles from the solar wind trapped by Earth's magnetic field.

The magnetosphere of Jupiter has three distinct regions. The inner magnetosphere, like that of the Earth, is doughnut shaped with the planet in the hole. It contains the intense, multishelled radiation belts in which three of Jupiter's big moons orbit and constantly sweep out particles. This inner magnetosphere extends about ten diameters from Jupiter; i.e., to about 1,400,000 km (900,000 mi).

A middle magnetosphere contains a current sheet of electrified particles moving out from Jupiter under centrifugal force, thereby stretching magnetic field lines with them. This disc extends between 10 and 30 diameters of Jupiter, to about 4,300,000 km (2,700,000 mi). These particles, which in the middle magnetosphere are mostly electrons, tend to be confined to a thin current sheet like a ring around the planet.

An outer magnetosphere lies between 30 and 45 Jupiter diameters (up to 6,400,000 km or 4,000,000 mi), but buffeting by the solar wind causes the magnetic fields to be irregular and the size of this region to fluctuate widely at differant times.

The spacecraft Pioneers 10 and 11 provided much information about this magnetic environment of Jupiter, which contains the plasma of electrons and protons surrounding the planet, and also how the solar wind interacts with it. The Voyager spacecraft in turn are expected to provide even better and more complete information about the region, including the position and shape of the bow shock. This shock is created where the magnetic field of the planet overrides the field carried by the solar wind. The two Pioneer spacecraft observed tremendous variations in the location of the magnetopause region between the solar wind and the field of the planet. These variations are still not thoroughly understood. The pressure of the solar wind varies a great deal at different times and it could be that these changes cause the fluctuations in the magnetopause observed by the Pioneers. To this end, the Voyagers' instruments will attempt to determine the extent and the physical characteristics of the electrons and ions forming the plasma within these three regions of the magnetosphere, particularly where the electrons change from being part of the inner magnetosphere, which rotates with the planet, and the region which is influenced by outward current flow to become a magnetotail streaming behind the planet in a direction away from the Sun. The tail has been detected as far away as the orbit of Saturn.

An important discovery of the Pioneer spacecraft was the strongly distorted nature of the outer magnetosphere. The general three-dimensional shape of the magnetosphere is still not thoroughly understood, because it is complicated by the rapid spin of the planet and the effects of the solar wind buffeting the magnetosphere. The Voyager mission will provide two more tracks of spacecraft through the complex magnetosphere and thus provide a better basis for our understanding of Jupiter's interaction with the solar wind.

There is a concentration of lines of magnetic force that extends from the surface of Jupiter to the satellite Io. This is referred to as a flux tube and it is somehow connected with the emission of radio waves from Jupiter. The origin of these decametric radiation bursts from Jupiter is still unknown, but it is believed that they may be connected in some way with instabilities of plasma within the ionosphere of Jupiter which are, in turn, caused by a flow of energy down the flux tube from Io. Scientists speculate that these enormous surges of energy might be detected by Voyager as ultraviolet emissions on the night side of Jupiter. Also, one of the Voyager spacecraft will fly through the flux tube and provide information about its true nature and the energy flowing along it.

STUDENT INVOLVEMENT

Project One: The Magnetosphere

Construct a miniature model of a magnetic field showing the field lines by placing a bar magnet beneath a sheet of white paper and then sprinkling iron filings on the paper. Shake the paper slightly and the iron filings will align themselves along the characteristic field lines. This shows the field two-dimensionally. To explore the three-dimensional field around a planet such as Jupiter, a model can be made by inserting a bar magnet through a hole in a rubber or styrofoam ball. The diameter of the ball should be the same as the length of the bar magnet.

Trace the magnetic field lines around your model planet by use of a small compass or a dip needle made by magnetizing a short length of iron and suspending it by pins so that it can rotate on a horizontal axis.

Demonstrate planetary rotation effects by suspending the ball representing the planet on a piece of thin twine. Tilt the axis of the bar magnet so that it is 11 degrees from the vertical axis about which the planet will rotate. Now observe what happens to the compass needle and the dip needle when they are placed at a fixed position a short distance from the planet and the planet is rotated. Your observation point (the location of the compass and dip meter) represents a spacecraft at a point on its path through the magnetosphere of the planet. Repeat your observations at several different points on a flyby trajectory.

Next suspend the planet model so that the bar magnet is vertical. Observe what happens when the planet is rotated about the same axis as the bar magnet. Do the compass and dip needle behave differently or the same?

Project Two: The Atmosphere

If organic molecules are discovered to be responsible for at least some of the colors in the clouds of Jupiter, it might be that organic chemistry could flourish beneath the clouds where temperatures may be the same as on Earth. Find out from Figure 7 the depth below the water ice clouds where the temperature is that in your classroom. What is the pressure in Jupiter's atmosphere at that level according to Figure 7? Is this pressure too great or too small for terrestrial life forms? From your knowledge of how weather circulates on Jupiter, describe what a Jovian life form might be like. How would it move around? Why would it have to move around? What might it eat, or how otherwise could it derive energy for its life processes?

Suggested Reading

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This is the third in a series of publications on the Voyager mission to Jupiter and Saturn. The first publication in the series was entitled *Voyager, Mission to the Outer Planets*; the second was entitled *Satellites of the Outer Planets*; a future issue will be devoted to the planet Saturn.

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Stock Number 033-000-00753-1

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