P76-10089

NASA News

National Aeronautics and Space Administration

Washington, D.C. 20546
AC 202 755-8370

Nicholas Panagakos
Headquarters, Washington, D.C.
(Phone: 202/755-3680)

Peter Waller
Ames Research Center, Mountain View, Calif.
(Phone: 415/965-5091)

RELEASE NO: 76-91

DISCOVERIES ABOUT JUPITER

Results from Pioneers 10 and 11 Combined with Earth-based Findings

NOTE TO EDITORS:

This fact sheet on major new findings about the planet Jupiter is based on presentations planned for a three-day Jupiter Science Symposium at NASA's Ames Research Center, Mountain View, Calif., May 24-26.

(NASA-News-Release-76-91) DISCOVERIES ABOUT JUPITER. RESULTS FOR PIONEERS 10 AND 11 COMBINED WITH EARTH-BASED FINDINGS (NASA) 61 p CSCL 03B

N76-24110

Unclas
00/91 40160

CONTENTS

JUPITER'S WEATHER

Scientists now believe they have worked out many of the main features of Jupiter's atmosphere and weather.

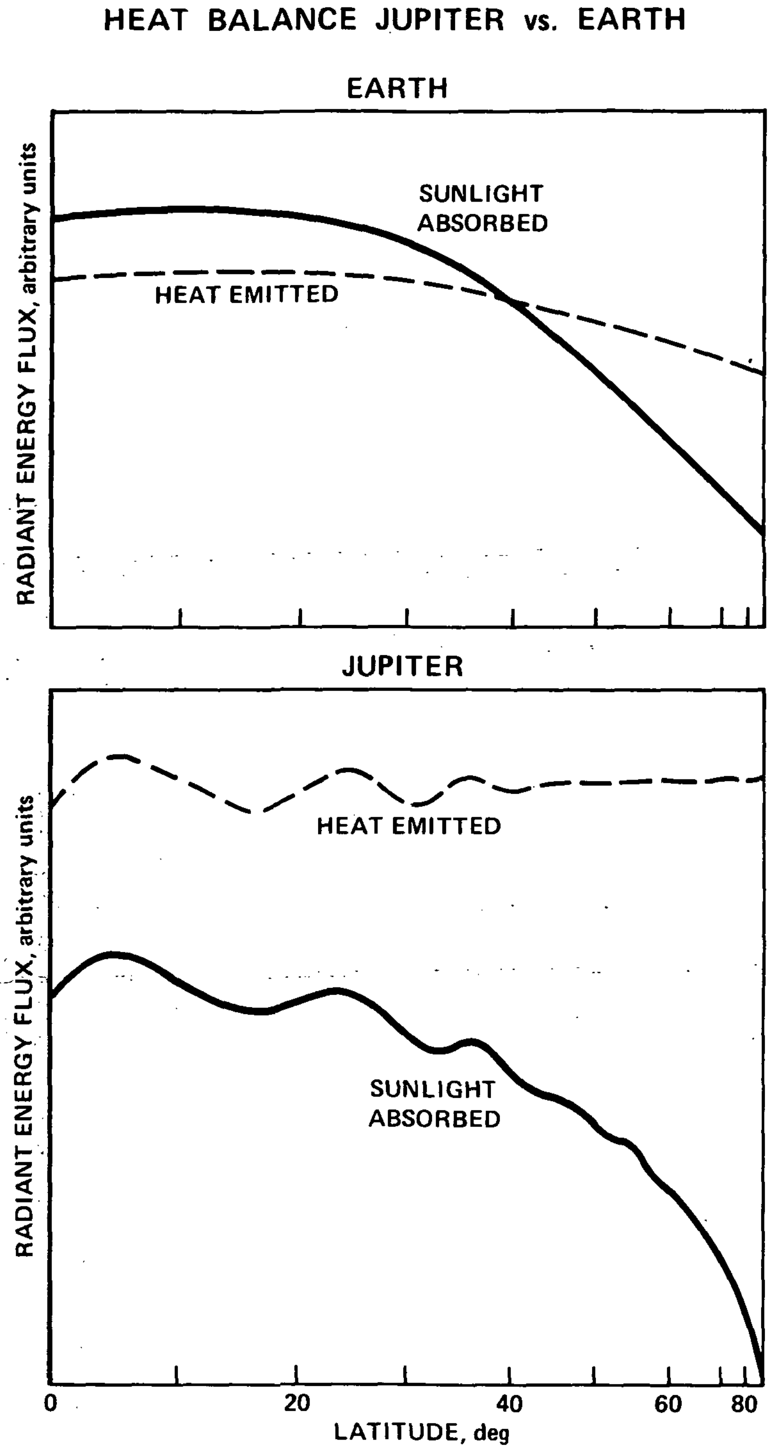
Instead of moving from equator to poles and back, as on Earth, Jupiter's weather circulation now seems either to be relatively local (in the polar regions), or to flow principally around the planet (in the temperate and equatorial regions). This means that weather circulation on the whole planet is somewhat like that in the Earth's tropics.

Pioneer 11 found that Jupiter's atmosphere appears to be heated uniformly from equator to poles, a major discovery, if it is confirmed. The Pioneer 11 pictures show that the planet's banded cloud structure breaks down above 50 degrees latitude, and turns into relatively small, mostly circular cloud features in the polar regions.

Unlike on Earth, every visible feature on Jupiter is a cloud, and cloud motions show atmosphere circulation.

Jupiter's colorful cloud bands, the belts and zones, now appear to be flow features typical of large, rapidly rotating planets in general. They are similar to the pattern of average circulation in the Earth's equatorial regions, a finding which may increase understanding of Earth's weather. Most atmospheric features on Jupiter have a life of decades and organized structures unknown on Earth. This makes the planet a unique laboratory for understanding all weather processes, including Earth's.

In Jupiter's polar regions, Pioneer 11's heat measurements and first pictures of the poles seem to show that polar weather patterns are something like those in the Earth's equatorial regions. They seem to be driven by atmospheric convection (rising of warm air, falling of cool) and condensation. The polar atmosphere contains great numbers of relatively small turbulent features, as well as large (1,600 kilometers (1,000 miles) across) circular features, which may be like relatively stationary versions of the large-scale cyclones in the Earth's temperate zones. These convective features probably represent the combined effects of the horizontal temperature gradients at the poles due to the large differences in solar heating there, and of Jupiter's interior heat driving masses of warm, moist atmosphere upward near the poles.



DRAMATIC DIFFERENCE between Jupiter's heat balance and Earth's is shown. In Earth's atmosphere, heat emission (dotted line) is roughly the same at all latitudes, while sunlight absorbed (solid line) is far higher at the equator. Solar heat reaches poles by atmosphere circulation. Since Jupiter has an internal heat source, it emits about the same heat at poles and equator, though sunlight is much greater at the equator. To even things up, extra internal heat moves through the planet's liquid interior and comes out at the poles. Bumps in Jupiter's heat emission line show belts and zones.

These two types of heating appear to form rotating cloud regions in the cool upper layers. The very strong coriolis forces at the poles probably add to the turbulence of these visible, little organized features.

In the temperate and equatorial regions, scientists also now can describe the internal circulation and composition of the giant planet's striking cloud bands, the white or blue-grey zones and the red-brown belts.

Furthermore, they feel they understand the role of coriolis forces and pressure gradient forces in maintaining the belts and zones. However, there are several competing theories for the specific driving mechanism of the overall weather pattern which produces the belts and zones.

Regardless of which of several proposed driving mechanisms it is that "stirs up" the weather in Jupiter's temperate and equatorial regions (below 50 degrees latitude), they all seem to produce the same result -- a banded planet.

Most experts now feel that weather in the temperate and equatorial regions is convective and appears to occur in a thin skin of atmosphere, which contains the planet's three major cloud layers. The bottom of this weather layer they believe is the base of Jupiter's water clouds. Below this is the relatively uniformly-heated deep atmosphere, consisting mostly of compressed hydrogen and helium gas. Below that is Jupiter's liquid interior.

The gradient of powerful coriolis (inertial) forces of Jupiter's high speed rotation seems to produce horizontal or two-dimensional flow in this upper "weather layer." Coriolis forces make the horizontal turbulence, induced in this layer by heating and condensation, stable in only one direction, tending to line it up east and west around the planet, parallel to the equator.

Convective cells appear to grow larger and larger, because large cells are less affected by turbulence than small ones, and hence tend to survive. Eventually these features grow large enough to girdle the huge, fast-spinning planet. This process probably is also found on Saturn.

Jupiter's production of cloud bands has been illustrated by Dr. Gareth Williams of Princeton University. Williams uses a detailed, self-consistent numerical computer simulation which starts with generalized large-scale turbulence of any origin over the whole planet. It reproduces the growth process of large cloud features, and ends by producing a Jupiter-like pattern of planet-girdling cloud bands.

The basic problem in explaining the precise driving mechanism which creates the planet's belts and zones concerns Jupiter's heat supply, a basic weather driver on all planets. Pioneer 11 found that somewhat more than 40 per cent of Jupiter's heat is internal heat, moving up through Jupiter's liquid hydrogen interior and dense gaseous atmosphere to the atmosphere top. The other nearly 60 per cent is heat absorbed from sunlight, mostly received in the equatorial and temperate regions.

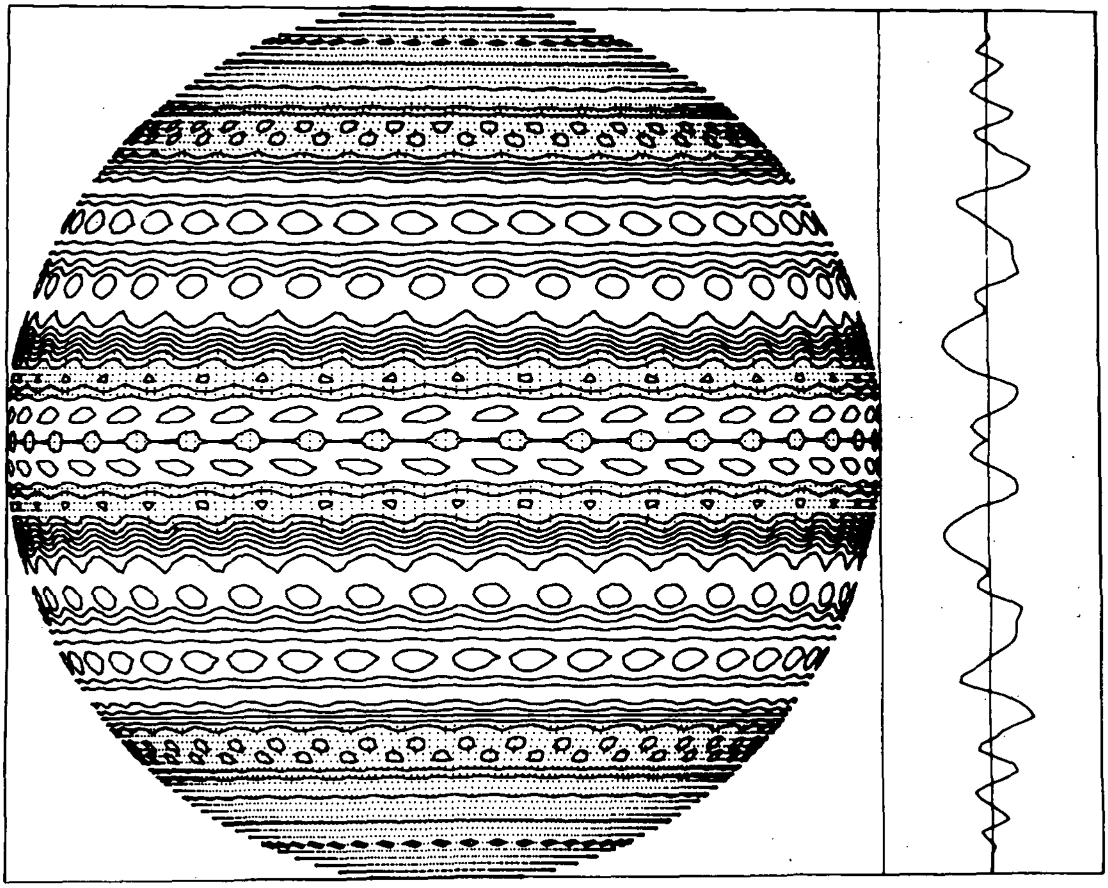
It now seems almost certain that much more of the heat coming from Jupiter's interior, and carried upward by convective circulation, reaches the top of the atmosphere in the polar regions than in the equatorial regions. Because Jupiter is a liquid planet, heat seems to distribute itself evenly throughout it. Since the poles receive less heat from the Sun, convection causes the rising internal heat to move more strongly to the cooler polar regions, until equatorial and polar temperatures balance. Internal heat, which starts toward the surface in the equatorial regions, seems to be blocked by solar heating of the equatorial atmosphere. This interior heat appears then to be shunted aside to the cooler polar regions, either somewhere in the liquid interior or in Jupiter's 960 km (600 mi.) deep gaseous atmosphere. This was first proposed by Dr. Andrew Ingersoll, California Institute of Technology, using Pioneer data.

The specific evidence for this internal heat flow is the Pioneer 11 infrared and radio occultation findings that Jupiter's atmosphere emits as much heat from the poles as the equator, and the Pioneer 11 pictures showing apparent convective features at the poles.

If atmosphere on Jupiter, warmed by the Sun's heat, were circulating from the equator north and southward to the frigid poles, as it does on Earth, the process should be visible in its cloud structure, and in its patterns of heat radiation. This is not the case, and hence most of Jupiter's solar heat appears to stay in the equatorial regions, along with about a third of its internal heat. Polar heating must come mostly from the interior.

-more-

JUPITER ATMOSPHERE SIMULATION STARTING WITH GENERALIZED TURBULENCE



TURBULENCE in Jupiter's atmosphere, regardless of source, smooths itself out into regular belt and zone-like patterns. This is shown by the detailed, numerical computer simulation of Dr. Gareth Williams, Princeton University. In right-side section, portions of wavy line to right of center line show winds faster than planet rotation rate, to left slower than rotation rate.

-more-

This means the large-scale circulator of Jupiter's visible atmosphere (the belts and zones) cannot be driven by flow of heated atmosphere to the poles (as many had thought), unless it occurs in deeper layers of the upper atmosphere than Pioneer 11 could see. Such flow would give the planet two kinds of atmosphere circulation one below the other.

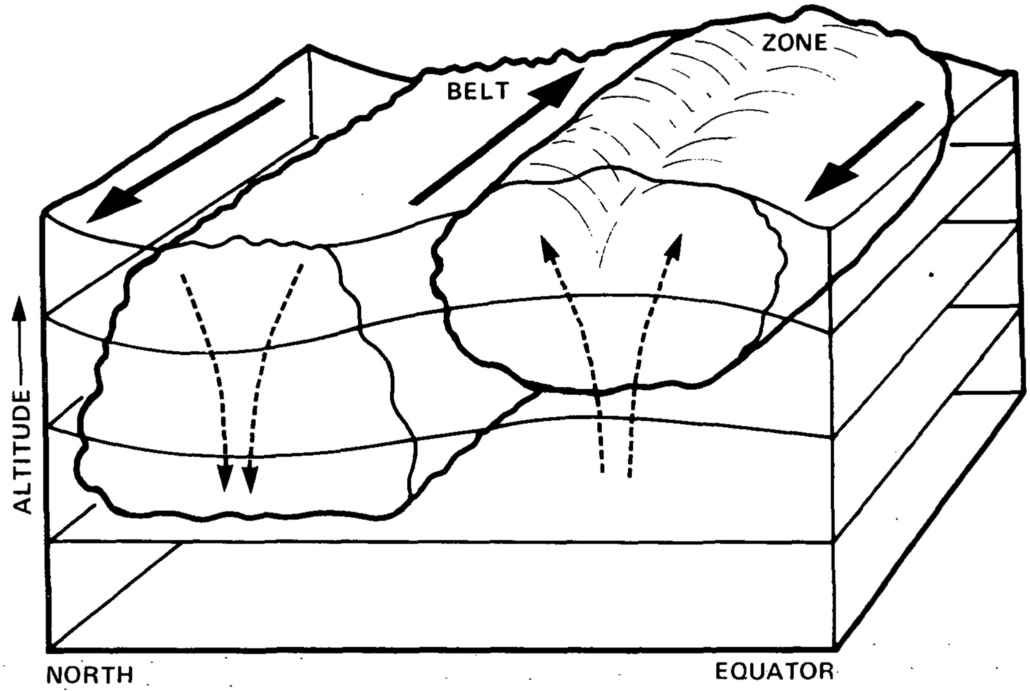
If, unlike on Earth, there is no flow of atmosphere from equator to poles, then the driver for Jupiter's large-scale weather features must be local heating.

A plausible current explanation for a local circulation pattern, supported by several researchers, is that first proposed by Dr. Peter Gierasch, Cornell University and Dr. Albert Barcillon, Florida State University, and worked out by Dr. Andrew Ingersoll, California Institute of Technology. This explanation suggests that the zones are like the large cyclones on Earth, but stretched completely around the planet. Like both cyclones and hurricanes, these mighty storm cells would be powered by the latent heat of condensation of water vapor. Water is believed present on Jupiter in amounts consistent with a solar mixture of elements. When rising water vapor cools and condenses out into rain, it always produces heat. This drives the atmosphere column containing it, upward higher and faster.

This heat of condensation would act as the driver, causing the atmosphere above to rotate more and more rapidly around the warm column. Rotation of the atmosphere above causes inward flow below the clouds; bringing in more and more moist Jovian air, and hence providing more and more latent heat. Columns would, therefore, steadily grow. At the same latitude columns would tend to join together to form bands (the zones) stretching around the planet. This tendency occurs because Jupiter's dominant coriolis force changes strength with latitude. The zones reach their final size at the balance point between generation of heat by moist convection and diffusion of heat by turbulence at the edges of the zones.

These stretched-out-cyclone bands (Jupiter's zones) are wider at the equator, the width being inversely proportional to the coriolis force. Dr. Ingersoll has developed a simplified numerical model and resulting Jupiter-like computer simulation of this latent heat mechanism.

CIRCULATION OF BELTS AND ZONES



JUPITER'S ZONES appear to contain warm, moist rising atmosphere, and the belts cool, dry, falling Jovian air. Air coming out of the tops of the zones spreads out toward the equator and poles, but coriolis forces cause the flow to turn 90°. Poleward flow goes east, equatorward flow west. (See next illustration.) This means that atmosphere in Jupiter's banded regions flows around the planet, not from equator to poles, as on Earth.

Direct evidence about the belts and zones fits the Ingersoll hypothesis (as well as some others). Telescope measurements of cloud movements over the past 20 years show that, relative to the whole planet, Jupiter's zones have strong winds, up to 320 kmph (200 mph).

On a rapidly-rotating planet like Jupiter, planet-girdling winds on the edges of the zones, by definition mean cross-zone temperature gradients. The reason is that coriolis forces convert motions toward or away from the poles into motions (winds) around the planet. As atmosphere rises in the zones and spills out the top in all directions, its north and south motions are converted by coriolis forces to flow east and west.

Regardless of how they happen, these winds blow around the planet in alternating directions and at speeds at zone boundaries which cause most observers to agree that the zones are regions of high pressure, warmer temperatures, rising motions, and enhanced cloudiness. While the belts are regions of lower pressure, cooler temperatures, descending motions, and are relatively cloud free. The Pioneer pictures seem to support this description. Various Pioneer measurements show that clouds in the zones are higher than the belts.

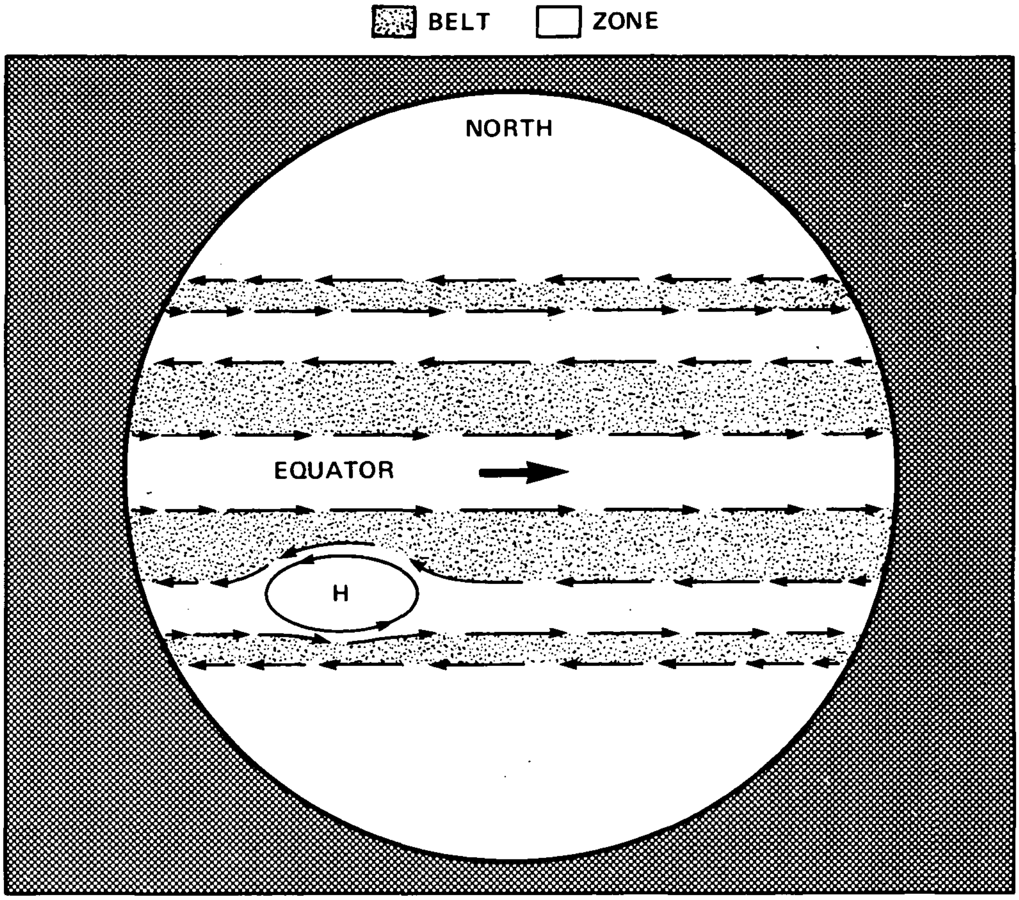
If the zones are planet-cyclone-like features, long strips of rising atmosphere, powered endlessly by the condensation of Jupiter's water vapor and its resulting heat, they would be much like the above description. The belts adjoining the zones would be similar to regions adjoining Earth cyclones, where the moist atmosphere sucked in, thrown upward and dried out (by raining) would then roll down the sides of the rising atmosphere column to eventually return to low levels, pick up the moisture, be sucked into the permanent cyclone of the zones again and perform the cycle all over again.

Small features on Jupiter as well as the Great Red Spot seem also in Dr. Ingersoll's view, to be hurricane-like features stretched out by coriolis force.

Another proposed driver derives from the possibility of a small equator-to-pole temperature difference. The Pioneer heat measurements are only accurate to 3 degrees C (5.4 degrees F.) so a temperature difference of this amount may exist. Such a difference could produce relatively small poleward flows of equatorial atmosphere.

-more-

JUPITER'S WINDS AT EDGES OF BELTS AND ZONES



JOVIAN WINDS (See preceeding illustration.) flow around the planet at the boundaries between the belts and zones due to coriolis forces and even distribution of heat all over the planet. At about 45^{o} latitude, belt and zone pattern breaks down.

-more-

Assuming such a poleward flow, Dr. Williams has been able to get an almost perfect Jupiter. Using a detailed numerical computer simulation of atmosphere flow, he has duplicated most of Jupiter's atmosphere features including the Great Red Spot.

Some researchers question certain assumptions about Jupiter's physical state required for this computer simulation. However, as noted, this one, and another computer simulation by Dr. Williams show clearly that assuming moderate-sized turbulent features, there is a numerical solution that will stretch them around the planet.

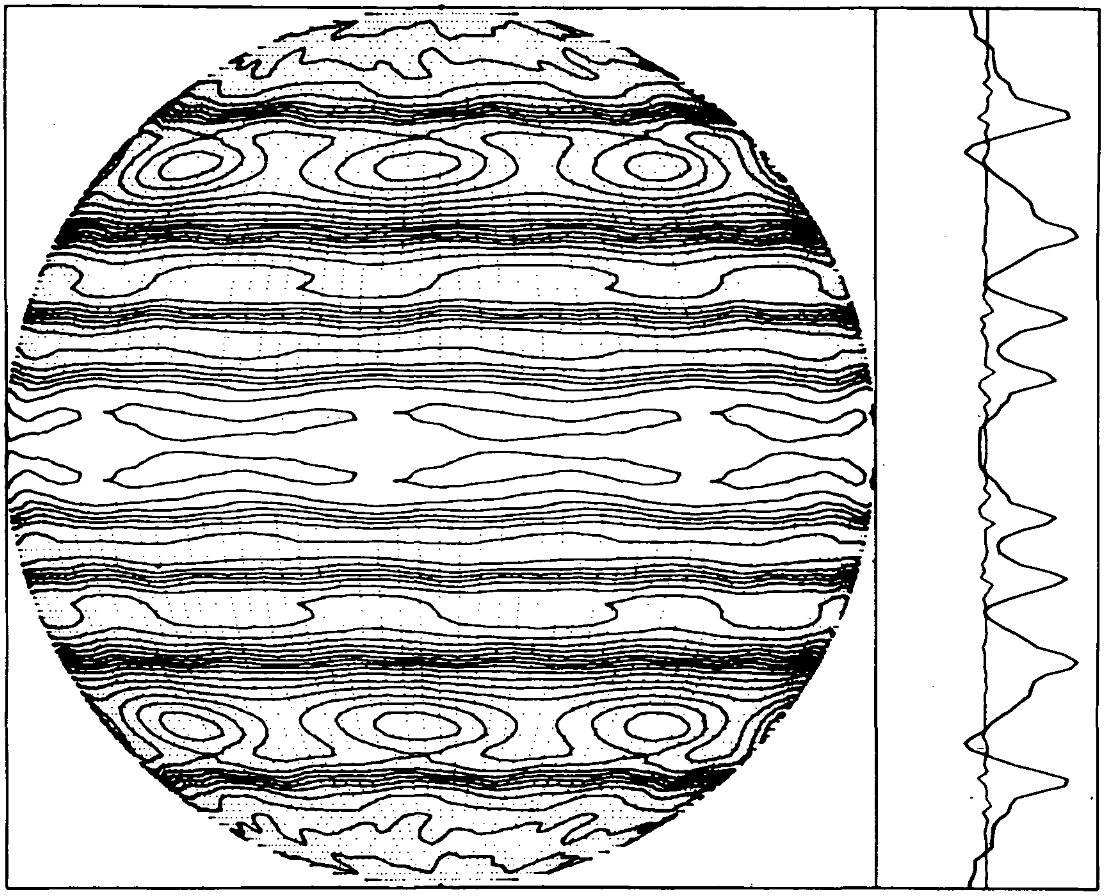
There are several other explanations for the driver of Jupiter's weather turbulence. Some researchers see the turbulence of the convective flow of Jupiter's atmosphere sorting itself out into the belts and zones, simply as a result of the size and curvature of the planet, its rotation speed, and the basic laws of fluid flow (i.e. the natural size of flow features on a planet like Jupiter).

Two such driver mechanisms are: (1) convection shaped by the temperature profile of the atmosphere, and (2) wind shears, turbulence created by the breakdown of hemisphere-wide flow patterns into counterflowing atmosphere streams (the zones and belts). Such wind shears should produce huge eddies 5,000 to 10,000 km (3,000 to 6,000 mi.) long, and these eddies at the boundaries between belts and zones are very clear in the Pioneer pictures, especially on the poleward sides of the temperate regions. Virtually all researchers agree that these eddies are wind shears, whether or not they are the dominant driving mechanism.

Still another explanation involves the fact that almost the entire interior of Jupiter is liquid and is undergoing convective flow to move heat from the deep interior to the surface. Jupiter's strong coriolis forces could organize this internal flow in the interior's outer molecular hydrogen region into differently heated rising and falling circulation zones.

The effects of this differential heating when it reached Jupiter's visible cloud layers could account for the upwelling of the warm zones and downflow of the cool belts. Because most thermal convection is small scale, and for other reasons, a number of researchers have reservations about this explanation.

SIMULATION OF JUPITER ATMOSPHERE FLOW
WITH GREAT RED SPOT



JUPITER'S GLOBAL CIRCULATION can be reproduced by applying the mathematical model for Earth weather circulation to Jupiter conditions. This detailed, numerical computer simulation by Dr. Gareth Williams, Princeton University, even includes Great Red Spot circulation patterns. In right-side section, portions of wavy line to right of center line show winds faster than planet rotation rate, to left slower than rotation rate.

-more-

Researchers believe that most of the processes mentioned above are present in Jupiter's atmosphere. The question is, which flow mechanism dominates? Further theoretical work and numerical computer simulation will help answer this, as will NASA's planned probe into Jupiter's atmosphere.

Various other aspects of Jupiter's weather features are as follows:

The basic differences between Jupiter and Earth weather are believed to be lack of a solid surface and internal heating. Size, gravity, rotation rate and chemical composition are all differences of degree. Both atmospheres contain condensible gas mixed with non-condensible gas.

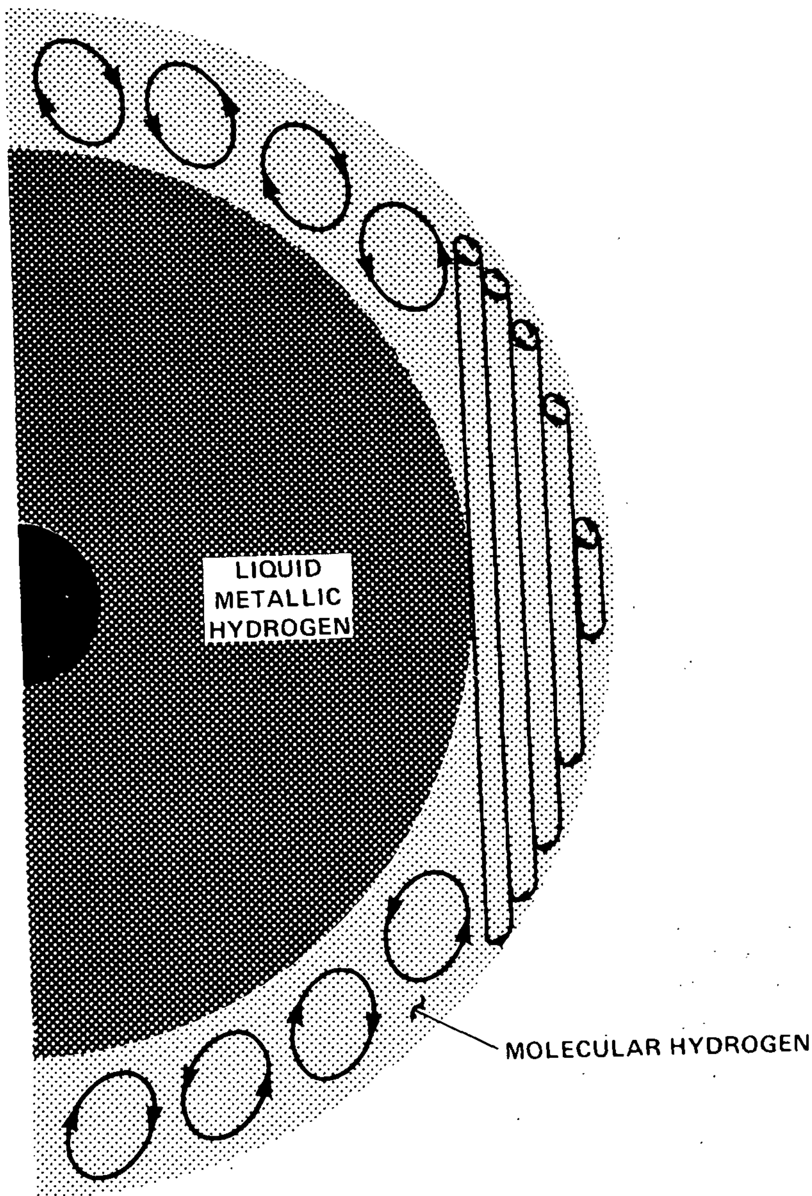
Jupiter's vertical atmospheric temperature profile of 2 degrees C per kilometer (2.7 degrees F. per mile) strongly suggests that the atmosphere is adiabatic, hence convective.

Because Jupiter is known to have "sun-like" ratios of carbon, nitrogen and helium to its hydrogen, from Pioneer and other measurements, most scientists think the mixture of elements on the planet is like that on the Sun.

The planet's permanent features appear to be to some extent "free wheeling" phenomena, requiring relatively small energy inputs. Clouds and atmosphere flow features apparently can go on unchanged for decades or centuries on Jupiter, many researchers believe, because of the nearly frictionless interface between the giant planet's think skinned 70-km (40-mi.) thick weather layer and the relatively uniform compressed atmosphere gas below the weather layer. Since, unlike on Earth, there is no solid surface at this easily deformable lower boundary, there is believed to be little or no circulation and no strong winds or large pressure differences at the bottom of the active atmosphere. This is something like flow in the oceans.

Features also persist and "free wheel" or coast because two-dimensional flow like Jupiter's is very inefficient at dissipating energy. Further, once Jupiter's largely hydrogen atmosphere has had energy put into it in the form of heat, it takes 20 times longer (over a year instead of a few weeks) to radiate this weather-driving heat away again, than it does in the Earth's oxygen and nitrogen atmosphere. Also, Jupiter's atmosphere receives only about 1/20th as much heat from both internal and solar sources as the Earth does from the Sun, so it takes much longer for temperature differences to develop.

PROPOSED MODEL OF JUPITER'S INTERIOR FLOW



CONVECTION PATTERNS proposed for flow of Jupiter's liquid interior. Near the poles, circular flow of liquid hydrogen by convection (rising of heated material) is conventional. In equatorial regions, experiments suggest a series of turning convective rolls, parallel to Jupiter's rotation axis. Convective flow would occur in the zone of molecular hydrogen, and cannot cross the boundary into the liquid metallic hydrogen region. Convective flow in a rapidly rotating liquid sphere is different than in a static liquid.

If heat is stored at the base of the atmosphere, there is much more gas to heat up and temperature differences would take decades to radiate away. Differences in speeds between counter flowing streams of atmosphere on Jupiter can produce winds as high as 600 kmph (360 mph). However, the total amount of flow of Jupiter's atmosphere is relatively small when compared with the planet's 35,500 kmph (22,000 mph) rotational speed and its huge size 436,800 km (273,000 mi.) circumference at the equator.

Jupiter's 70 km (40 mi.) thick weather layer contains three main layers of clouds with various sub-layers. The weather layer is believed to lie between pressure levels of .5 Earth atmospheres at the top and 4.5 Earth atmospheres at the base.

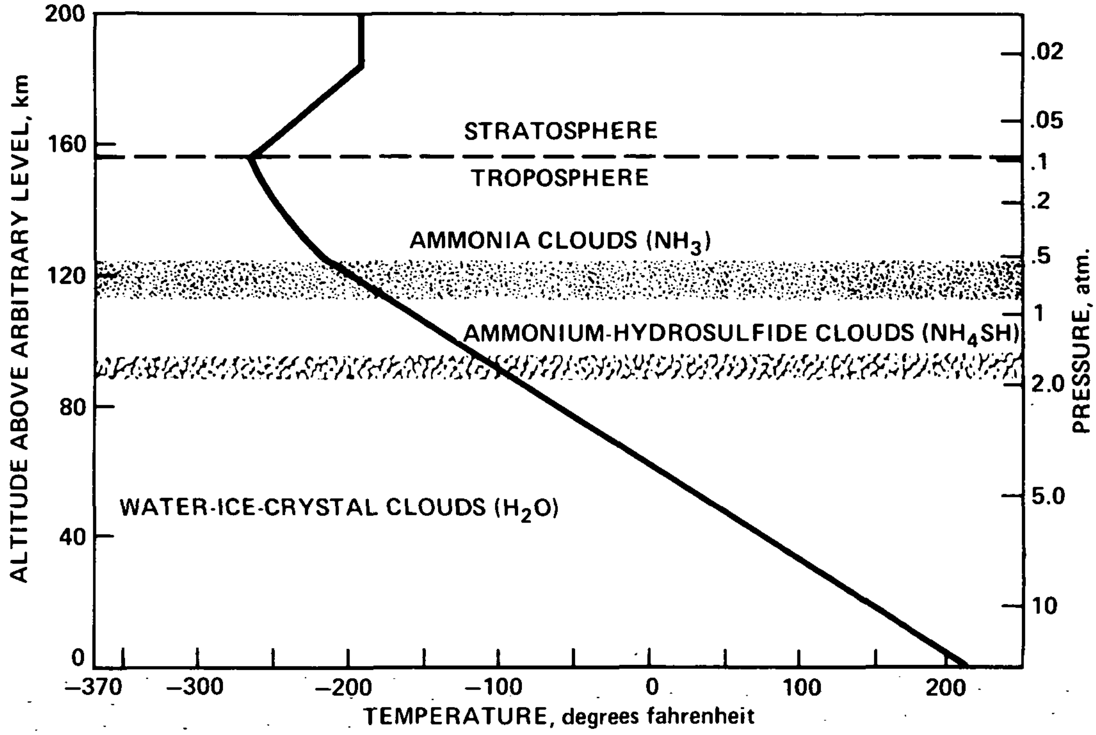
From the top down, mostly according to spectroscopic measurements from Earth, clouds are: a layer of ammonia crystals and aqueous ammonia, below that a layer of ammonia hydrosulfide crystals, and below that water ice crystals and water vapor. The very highest clouds are the deepest reds (like the top of the Great Red Spot) and are believed colored by traces of phosphorous. Next highest are white clouds (ammonia cyrstals). Below the white clouds are gray or brown clouds (believed to be made of sulfur compounds, hydrogen and ammonia polysulfides, or complex organic molecules. The variation in cloud colors seen on Jupiter indicates various sub-layers reflecting condensation at various temperature and pressure levels.

Below a pressure of 4.5 Earth atmospheres, the atmosphere, made 99 per cent of compressed hydrogen and helium (ratio 88 to 12) is believed to be uniformly heated and mixed down to deep levels, as a result of convective flow from Jupiter's hot interior. When pressure has risen to 100 atmospheres, temperature is 1,000 degrees C (1,900 degrees F.) (see Jupiter's Interior).

The water clouds, where water condenses out and latent heat of condensation is added, may form a kind of transition region between the uniformly mixed lower region and the upper weather region.

The weather layer's frictionless lower boundary is believed to be totally unlike the Earth's where winds scrape against relatively dense liquid water or a rough solid surface of continents, and in the Americas, a fence of high mountain ranges almost from pole to pole.

JUPITER'S ATMOSPHERE AND CLOUDS



VERTICAL CLOUD STRUCTURE of Jupiter's atmosphere, according to Dr. John Lewis, MIT. In an atmosphere of uncondensible gases (hydrogen and helium), there are distinct layers of clouds (condensible gases) at various temperature and pressure levels. Line shows temperature of the atmosphere at various altitudes and pressures, based on infrared measurements.

Details of Jupiter's upper atmosphere also based on spectroscopic measurements of various atmosphere layers are now believed to be as follows:

The top cloud layer of ammonia ice crystals is at a level where pressure is .7 of an Earth atmosphere and temperature -120 degrees C (-184 degrees F.), the pressure-temperature combination at which ammonia would condense out. This can be called Jupiter's visible cloud tops, and is at the base of Jupiter's stratosphere.

Pioneer light-scattering measurements show that cloud top particles in both the belts and zones are similar. Particles are quite large (one micron or more), very reflective and are crystals (probably ammonia ice). Differences in particles are primarily in color. The belts are darker in color (not heavy with aerosols), and hence reflect less light.

Scattering measurements also show a very high layer of large, reflective particles in the upper atmosphere. Below this is transparent atmosphere, and below that, one or many relatively thick cloud layers.

Light scattering seen at the poles, such as the clearly "blue sky" there, and the much better Pioneer pictures in red than blue light, suggests that the transparent atmosphere above the clouds could be three times deeper above 60 degrees latitude than at the equator, and hence scatter blue light. More likely, these effects are due to a thin cloud layer in the upper atmosphere at the poles.

Various measurements agree with this profile. They suggest that the transparent atmosphere above the clouds contains some ammonia, plus some well-mixed methane.

Fourteen km (8 mi.) above the cloud tops at .3 atmospheres pressure temperature is down to -145 degrees C (-229 degrees F.). Still farther out, a haze of ammonia crystals may exist, extending up to a layer where solar heat is absorbed by the atmospheric methane. This may well account for the inversion layer, where the atmosphere begins to warm up with height instead of cooling off. The inversion layer at .1 Earth atmosphere is 35 km (21 mi.) above the cloud tops, and temperature there is -155 degrees C (-247 degrees F.).

Still higher there appears to be a haze of aerosols (droplets) and hydrocarbons such as the recently identified methyl radicals, ethane, acetylene and phosphene, which also may absorb sunlight and heat up the atmosphere.

While these details of the outer atmosphere are of great interest, atmosphere gas above a pressure of .5 Earth atmospheres is too diffuse to have pronounced effects on Jupiter's weather.

At pressure level of .5 Earth atmospheres, Jupiter's atmosphere which has been cooling rapidly with height begins instead to cool very slowly as one goes up. This produces a very stable layer and according to some researchers, may account for the two-dimensional flow of the layers below it, since there are no strong forces to counteract the pattern set by this stable upper layer.

THE GREAT RED SPOT

The Great Red Spot now appears to be a free-wheeling atmosphere and cloud feature on Jupiter.

It apparently has been turning counterclockwise, like a three-times-Earth sized gear wheel, "forever," or at least for the past 300 years, between the counterflowing north and south halves of the South Tropical Zone, which it splits.

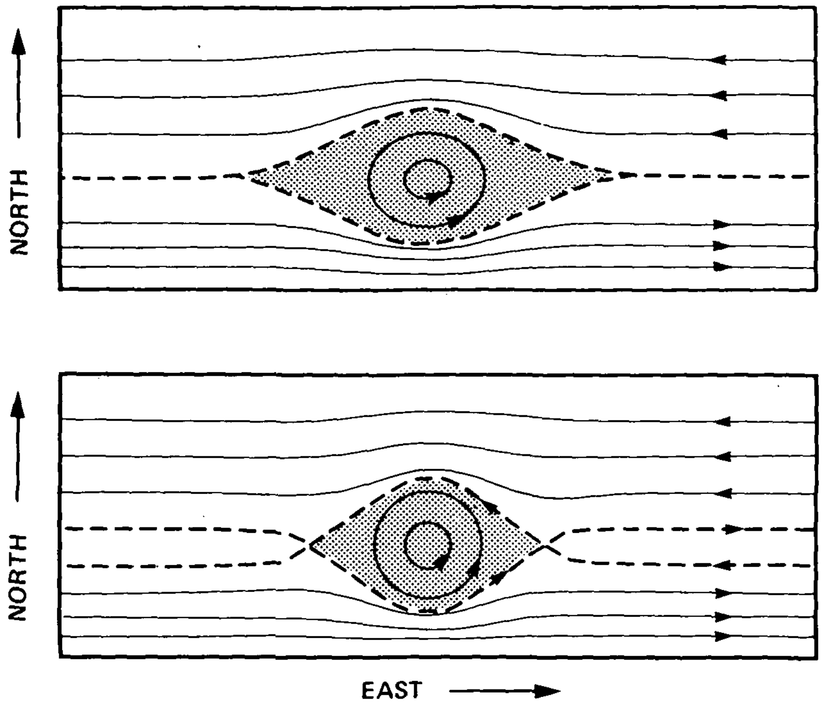
Pioneer measurements appear to show that the enormous red cloud topping the Great Red Spot is the highest cloud feature on the planet, rising some 8 km (5 mi.) above the surrounding cloud deck. At this height, Jupiter's atmosphere has cooled enough that, it is believed, traces of phosphorous in the upwelling atmosphere of the spot condense out, providing the deep red color.

The spot has drifted irregularly westward over the years, confirming ideas that it is a product of atmosphere circulation rather than being fixed to one point on the planet.

Nearly all Jupiter atmosphere authorities agree that the zones are bands of rising warm moist air, whose poleward and equatorward edges flow in opposite directions. Since the spot is in the center of a zone, and presumably like the zone surrounding it, it is probably a column of rising atmosphere. Dr. Andrew Ingersoll of Cal Tech calls it a "super zone," which rises even higher than the other zones. This idea is further borne out by the existence of other smaller red spots in the center of zones. (Four have been found and studied since 1974.)

Most researchers now believe the spot "free wheels" between the counter-flowing motions of the zone halves north and south of it. They point out that without an energy dissipation mechanism, the spot could theoretically last forever. The small amount of energy dissipated by the spot's vertical motion is not enough to change this free-wheeling flow pattern appreciably. (All Jupiter weather tends to last a long time. See Jupiter Weather story.)

FLOW AROUND GREAT RED SPOT



THE GREAT RED SPOT as modeled by computer agrees with time-lapse observations from Earth. The top view shows counter-clockwise winds around the spot, pointed tips on either end of the spot, and east-west wind flow north and south of the spot. Bottom view shows how smaller dark spots can change latitude and begin to recede in the direction they came from. Simulations are by Dr. Andrew Ingersoll, Cal Tech.

-more-

Dr. Ingersoll explains that while the atmosphere gas forming the spot almost certainly rises, and descends around the edges, dissipating negligible amounts of energy, these motions are too small to measure. By far the most vigorous motion is the high-speed flow of atmosphere streams around the spot.

Using a computer model, Ingersoll found that the rolling-wheel configuration was the only one that gave a permanent spot. This simulation also gave the spot pointed tips at east and west ends, and these are clearly visible in the Pioneer closeup pictures.

Drs. Tony Maxworthy and Larry Redekopp, University of Southern California, have taken a similar approach, successfully duplicating other flow features around the spot.

The simulation shows how other large spots should interact with the Great Red Spot, as the Red Spot and these other spots pass each other due to slightly different eastward velocities. Details of this interaction are predicted in their theory. These include speed up of the Red Spot and smaller spots toward each other once they come close -- and emergence without change in shape of either the Red Spot or the passing spot. These details have actually been observed in photographs of Jupiter. The two spots come together. Their flows appear to mix in some way. They flow around each other and emerge as they were when they started.

Maxworthy and Redekopp call these spots "solitary waves" because they represent one wave crest and no neighboring wave crest.

-more-

JUPITER'S MAGNETOSPHERE AND RADIATION BELTS

The basic mechanisms of the huge magnetic envelope enclosing both Jupiter and its intense radiation belts now appear to have been explained by Pioneer experimenters.

Jupiter's magnetosphere has a million times the volume of the Earth's. At times it is 21 million km (13 million miles) in diameter. The radiation belts it contains are 5,000 to 10,000 times as intense as the Earth's Van Allen belts, and total energy of their high-energy particles is many millions of times that of the particles in the Earth's belts.

The tremendous intensities of Jupiter's inner radiation belts appear to be due to constant recirculation of their particles, with an increase in energy each time around. This is a new discovery.

Particles from the belts appear to move to the turbulent outer magnetosphere on field lines connected to the poles, says Dr. James Van Allen, University of Iowa. There they are redirected by snarled magnetic fields, and part of them move back in to the inner radiation belt via the central current sheet field. (See drawing.) This inward motion increases their energy, and they repeat the process over and over, gaining more and more energy. Many of the particles are absorbed by impact with Jupiter's four inner moons, but those that escape eventually have tremendous energies.

A second major finding is that the entire magnetosphere behaves like an enormous, fast-rotating leaky bag. High-energy electrons apparently escape from all parts of the bag's surface, says Dr. John Simpson, University of Chicago, and many of those electrons appear to be seen as far in as the Planet Mercury. Power needed for acceleration of these electrons is 100 billion watts. This makes Jupiter a major source of high-energy electrons in the solar system, and also helps explain the character of Jupiter's magnetosphere.

The principal characteristics of the magnetosphere and its radiation belts are:

1. The particles in the radiation belts appear to get their tremendous energies by constant recirculation from the inner radiation belts out to magnetosphere boundaries, and back to the inner belts. The particles get steady increases in energy from this process, according to Dr. James Van Allen, University of Iowa.

2. The mechanism which gives the particles their energy depends in part on Jupiter's high velocity rotation, and hence the high velocity rotation of its magnetosphere. The continuous buffeting and shaking up of this huge spinning bag of particles (the magnetosphere), as it bumps and rubs constantly against the continuous pressure of the solar wind interrupts the regular mirroring of particles from pole to pole along magnetic field lines and throws them inward toward the planet, recirculating and energizing them.

The outer skin of Jupiter's magnetosphere moves about two and a half times as fast around Jupiter's axis, as the million mph speed of the solar wind as it comes in from the Sun.

Increases in solar wind pressure often squeeze down the volume of the spinning magnetosphere as much as eight times.

3. The belts would be 100 times more intense without the soaking up of most of the high energy particles by Jupiter's big moons and the top of Jupiter's ionosphere, and the squirting of particles out of the leaky bag of the magnetosphere during this recirculation process.

4. The basic source of the particles in the belts is probably the ionized top of Jupiter's atmosphere (the ionosphere) not the solar wind, Dr. Van Allen believes.

5. Jupiter's magnetosphere is so big because relatively low energy particles spun off the top of the ionosphere stretch it out. These particles are thrown by the centrifugal force of Jupiter's rotation far out from the planet. The stretching of magnetic lines of force by these outflowing ionized particles makes the magnetosphere more than twice as big as it would be if it were created only by the force of Jupiter's magnetic field holding the ionized gases of the solar wind away from the planet.

6. Jupiter's magnetosphere is like a huge leaky bag that appears to be releasing bursts of electrons, says Dr. Simpson. The observation of a ten-hour period makes it almost certain that the mechanism involves the offset of Jupiter's rotating magnetic field. It may be that the electrons escape from Jupiter's magnetosphere both over the poles and through the magnetic boundary of the magnetosphere as the solar wind presses on it.

A rough analogy, says Simpson, may be that the leaky bag of the magnetosphere appears to get an extra hard squeeze once every ten hours (once every planet rotation or Jupiter day). This regular squeezing seems to stir up the electrons inside the bag and forces some electrons through the very weak skin of the bag at many latitudes.

Source of this squeezing, says Simpson, is probably the fact that the bag is not spherical, but in some way lopsided (probably because Jupiter's field is lopsided). This once-per-rotation squeeze means that the spectrum of electrons squirted outward by Jupiter changes every ten hours, and at the same time, electron energy increases inside the magnetosphere every ten hours.

7. The outflowing low energy particles, and the magnetic field they create, become very weak at the magnetosphere boundary, 10 million km (six million mi.) from the planet. Because of this weakness, high-speed gusts of the solar wind often force the skin of the magnetosphere back half the distance to the planet. Once begun, this pushing-back process itself appears to force the field to collapse. During such a collapse, the magnetosphere boundary can move back as fast as 32,000 kmph (20,000 mph).

Cancellation of magnetic field lines by this process or by rotational squeezing can accelerate particles to near light speeds, and squirt them at least as far as the Earth. This makes the planet and the Sun the only known important sources of high energy particles in the solar system.

8. Usually the spinning magnetosphere is believed to resemble a huge comet, with the blunt end pointed at the Sun, and the tail or effects of the tail reaching out beyond Saturn's orbit almost half a billion miles, says Dr. John Wolfe, Pioneer Project Scientist. The magnetosphere is usually about as thick in the dimension parallel to Jupiter's axis, as twice the distance of its sunward boundary from the planet.

Magnetosphere Mechanisms

The recirculation of particles in Jupiter's magnetosphere appears to create the radiation belts. It seems to work something as follows:

Jupiter's inner magnetic field and intense inner radiation belts are much like those of the Earth, and have the same doughnut shape with the planet in the hole. Jupiter's magnetic field at the planet's cloud-tops has more than ten times the strength of the Earth's field at the Earth's surface. Total energy in the field is 20,000 times that of the Earth's field.

This very strong field traps radiation just as Earth's does and controls particle movement very strongly. Particles bounce constantly from one of the planet's magnetic poles to the other in a few seconds, following the magnetic field lines.

The big difference from the Earth is that Jupiter's three big inner moons, especially Io (innermost big moon), move through the heart of the radiation belts and absorb most of the heavy protons as they bounce from pole to pole along the field lines. Particles not absorbed are the ones whose trajectories around the field lines keep them out of the paths of the moons' orbits.

Without this absorption of 99 per cent of the protons, spacecraft travel near Jupiter would probably be impossible.

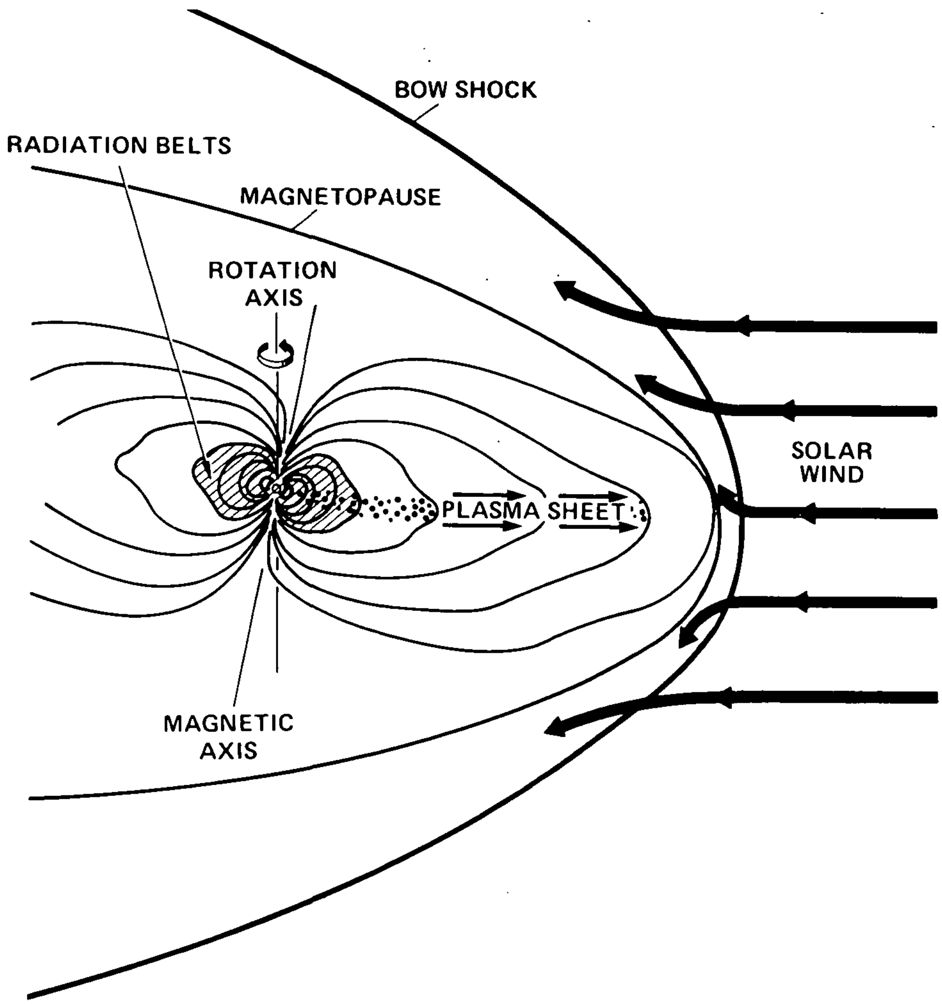
The acceleration mechanism for particles in the inner radiation belts depends on the outer magnetosphere:

According to Dr. Van Allen, ionized particles are spun off the top of the planet's ionosphere. They then move out along field lines and become trapped along the equatorial plane of Jupiter's magnetic field, which is tilted 11 degrees to the rotational equatorial plane because Jupiter's field is tilted 11 degrees.

These particles flow out as a flat equatorial ring or sheet. Since moving ionized (electrified) particles produce an electric current, the particle sheet is also a sheet of electric current. Since an electric current also produces a magnetic field, the current sheet produces a flat, weak magnetic field (1/20,000 Gauss) ringing the planet, which combines with Jupiter's internally-generated magnetic field.

Ionized particles follow the field lines outward in this flat ring field or magnetodisc another 30 Jupiter diameters. At this point, they reach the outer magnetosphere, which is about 15 Jupiter diameters wide. There the field is much distorted by buffeting of the solar wind. This constant flow of low energy electron and proton (plasma) into the outer magnetosphere tends to blow it up larger and larger, until a heavy gust of solar wind squashes it back down again.

JUPITER'S MAGNETOSPHERE



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 the centrifugal force of Jupiter's high-speed rotation, 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° of sky, compared to the Sun's .5° of sky.

The intense energies of particles in the inner belts and elsewhere are due to the flow of high energy particles in all three parts of Jupiter's total magnetosphere.

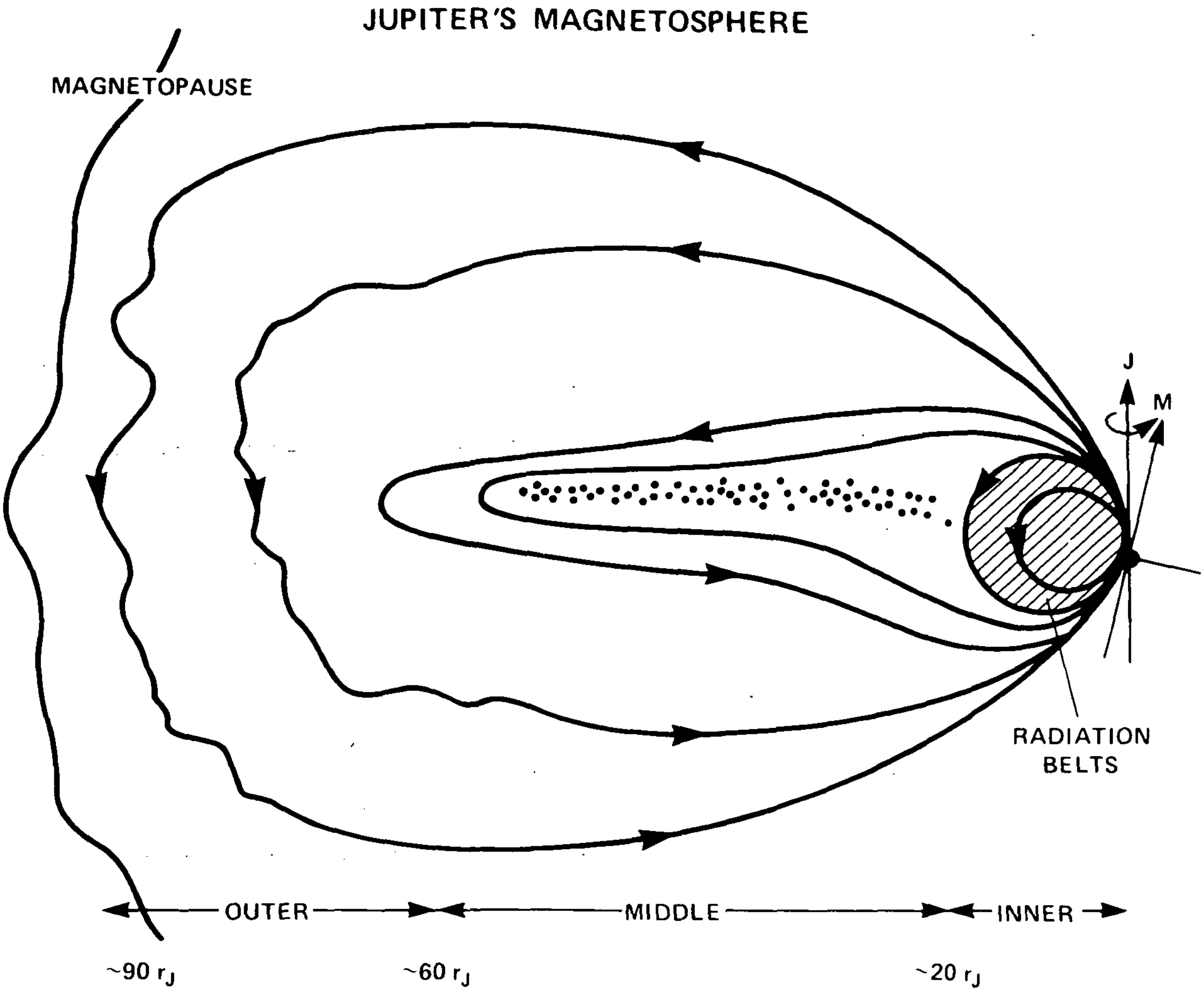
High energy particles in the intense inner radiation belts mirror back and forth between Jupiter's poles. At the poles themselves, the magnetic field lines are very close together, like a bristly cap emerging from the planet. Hence, at the poles, particles can switch field lines. Many eventually move from a field line close in to the planet to one which skirts the outer edge of the magnetosphere.

In the outer magnetosphere, the constant buffeting by the solar wind, plus the high-speed rotation of the magnetosphere shake up the huge bag of the magnetosphere, snarling up magnetic field lines and hence scattering high energy particles in many direction, deflecting them from their regular loop paths between the poles.

These disoriented particles then tend to move inward toward Jupiter along the current sheet, gaining energy as they go. The reason for this inward diffusion is that as particles are soaked up by the big moons or Jupiter's ionosphere, a low particle pressure region (a region of fewer particles) is created in the inner belts. Because of this lower particle pressure, outer belt particles are drawn in toward the inner belts and shift from field line to field line. Particles moving inward, into a stronger field and following shorter magnetic field lines, gain energy (speed), a three time increase for every planet diameter closer to Jupiter.

When the particles, energized by their inward movement from field line to field line, reach the inner belts again, they continue to mirror between the poles, and many of them move onto an outer magnetosphere field line at the poles and return to the outer magnetosphere. They repeat this cycle over and over. The particles gain energy as they move in by moving from one field line to another. They do not lose energy going out because they stay on the same field line until they reach the turbulent outer magnetosphere.

This recirculation process is continuous. Particles follow a field line out to the outer magnetosphere, diffuse back in along the current sheet, picking up energy simply from the inward movement, move out again on just one field line, pick up still more energy and so on.



PARTICLES IN JUPITER'S RADIATION BELTS are believed to get their tremendous energies by recirculation within the magnetosphere. Particles move to the turbulent outer magnetosphere along magnetic field lines connected to the poles. There, many of them are thrown inward by turbulent magnetic fields, and move back close to the planet along the current sheet field, gaining energy in the process. They then return to polar field lines, and repeat the process, gaining added energy each time, until eventually their energies become extremely high.

All this means that the huge intensity of Jupiter's inner radiation belts is due to the fact that particles in a planetary magnetic field always pick up energy as they move in toward the planet.

The particles constantly recirculating and gaining energy, are steadily taken out of circulation by impact with Jupiter's big moons, the top of the ionosphere, or breaking out of the leaky bag of the magnetosphere into interplanetary space.

It is the surviving very-high-energy particles which form Jupiter's powerful radiation belts.

Pioneer Findings

Jupiter's Magnetic Field

Strength - 17,000 times Earth's field

Total energy - 20,000 times Earth's field

Tilt - about 11 degrees to Jupiter's rotation axis

Equatorial intensity - 4.2 Gauss at Jupiter's cloud tops. (Earth's field strength at the surface is .35 Gauss.)

Polar intensity - 14.8 Gauss, north pole - 11.8 Gauss, south pole.

Offset - Center of the field does not coincide with the center of the planet. It is one tenth of a Jupiter radius 7,140 km (4,280 mi.) away from the planet center toward 5.12 degrees N. latitude. This is 700 km (420 mi.) north of the planet center and 7,100 km (4,400 mi.) outward from the rotation axis in a direction parallel with the equator. Because of the field's offset, field strength over the cloud surface varies from 3 to 14 Gauss.

Wobble - Because Jupiter's magnetic field is tilted 11 degrees to the planet's rotational axis, the entire field and the radiation belts it contains wobble up and down through an arc or 22 degrees once every ten hour rotation of Jupiter.

Jupiter's Radiation Belts

Jupiter's inner radiation belts have the highest intensity ever directly observed by space measurements, comparable to intensities of high altitude nuclear explosions. Total energy of particles in the belts is many millions of times the total energy of those in the Earth's Van Allen belts.

The belts are a great hazard to spacecraft flying close to the planet or orbiting it, though flight paths can be planned to miss the worst radiation. Three of Jupiter's four planet-sized moons lie within the intense inner radiation belts, making manned landings on them very difficult.

The fourth big moon, Callisto, lies outside the region of intense radiation, and would be somewhat more feasible for a manned landing.

Because of its flight path close to the center of the radiation belts, Pioneer 10 received more radiation than Pioneer 11, even though Pioneer 11 came much closer to the planet. The radiation belts are most intense near the equatorial plane of Jupiter's magnetic field. Pioneer 10 received about 100 times the lethal dose of radiation for humans, close to the limit of radiation tolerance for spacecraft systems. Peak intensity was one billion electrons per square centimeter per second striking the skin of the spacecraft. Ninety per cent of these electrons were from 3 million to 30 million electron volts energy.

Pioneer 10 received six million protons per square centimeter per second. Pioneer 11 came 97,600 km (61,000 mi.) closer to Jupiter than Pioneer 10, only 41,600 km (26,000 mi.) above the cloud tops, and encountered proton intensities 20 times greater. However, these high-energy protons were in thin shells, so that the spacecraft sliced quickly through them. Electron intensity levels for Pioneer 11's closer pass were about the same as for Pioneer 10. Scientists doubt that a closer approach to the planet than Pioneer 11's would find greater radiation intensities.

Both Pioneers found dips in the intensity of radiation at the orbits of Io and Amalthea, as these moons absorbed high-energy particles.

All of Jupiter's really damaging radiation is found in the inner magnetosphere within about 1,440,000 km (900,000 mi.) of the planet, though the mechanisms of the middle and outer magnetospheres are responsible for producing the high-intensity radiation close to the planet.

The greatest radiation intensities in the inner belts coincide with the equatorial plane of Jupiter's magnetic field. Going north or south from the magnetic equator, radiation intensity falls three times in the first 20 degrees of Jovian latitude, and ten times in the first 40 degrees of latitude. The closer one comes to the planet, the more tightly particles are confined to the magnetic equator.

Intensity of electrons increases ten times for every 211,000 km (132,000 mi.) one moves closer to the planet, but peaks and then levels off at 64,000 (40,000 mi.) above Jupiter's cloud tops. For protons, there is a similar intensity increase up to 18,000 km (30,000 mi.) from the visible surface, and then a substantial decline.

The offset of Jupiter's magnetic field probably creates a particle-free region between the top of the ionosphere and 7000 km (4,400 mi.) out. This is analogous to the action of an eccentric cam mechanism.

Jupiter's Magnetosphere

Bow Shock Wave

Like the Earth, Jupiter has a bow shock wave produced when the million-mile-an-hour solar wind rushing out from the Sun strikes the planet's magnetosphere and flows around it. There is also a turbulent transition region, like Earth's, inside the bow shock front, and within that an enclosed magnetosphere or magnetic envelope, somewhat like Earth's, created by Jupiter's magnetic field. The solar wind cannot directly penetrate this magnetosphere.

These phenomena at Jupiter are on a scale never before seen.

A line from one side of Jupiter's bow shock wave to the other, passing through the planet's day-night boundary can be as long as 26.4 million km (16.5 million mi.), about 80 per cent of the distance between the orbits of the Earth and Venus.

Jupiter's magnetosphere is equally huge. It has an average diameter of 14.5 million km (9 million mi.). If it could be seen from Earth, more than three quarters of a billion kilometers (half a billion miles) away, it would occupy two degrees of the sky, compared with only half a degree of the sky occupied by the Sun.

The magnetosphere appears to be shaped like a comet with the blunt end toward the Sun. Its vertical thickness (parallel to Jupiter's axis) usually equals twice the distance from the planet of its boundary on the Sun side.

Within the magnetosphere, density of trapped low energy particles (plasma) is ten times as great as in the solar wind outside it. The entire magnetosphere appears to rotate at high velocity along with the planet, and the outer skin of the magnetosphere may well rotate at about 4 million kmph (2.5 million mph) around Jupiter's axis--although some scientists think that the outer regions may rotate more slowly than the inner regions, which rotate as though rigidly attached to Jupiter.

The magnetosphere varies constantly in size, pulsating like a cosmic jelly fish with changes in solar wind pressure. Due to this constant pulsation, Pioneer 10 crossed Jupiter's bow shock wave 17 times as it left the planet. Pioneer 11 crossed it three times inbound and three times outbound.

Within the magnetosphere, there are three separate regions:

1. The inner magnetosphere like the Earth's is doughnut-shaped with the planet in the hole. It contains the intense, multi-shelled inner radiation belts in which three of Jupiter's big moons are embedded. The moons constantly sweep out particles. Radiation is very stably trapped, and lifetimes may be as long as several years. The inner magnetosphere extends ten planet diameters, 1,440,000 km (900,000 mi.) from the planet.

Near the orbits of Ganymede and Io in the inner belt, Pioneer 11 saw several hours of powerful, one-minute bursts of high energy particles. This indicated local particle acceleration processed.

2. The middle magnetosphere contains the magnetodisc or current sheet. This is a disc of electrified particles extending from ten to 30 Jovian diameters 1,340,000 to 4,320,000 km (900,000 to 2,700,000 mi.) from Jupiter. Ionized particles forming this sheet come from the top of Jupiter's ionosphere and because of the centrifugal force from Jupiter's rapid rotation are forced to concentrate near the planet's tilted magnetic equator. In the middle magnetosphere, the flow of electrified particles in the current sheet produces a disc magnetic field stronger than Jupiter's internally-generated field. In the middle magnetosphere, particles (mostly electrons) tend to be confined to the thin 700,000 km (420,000 mi.)-thick current sheet.

Earth receives more radio noise from Jupiter than any other source except the Sun. Three kinds of signals are heard: 1) thermal - from the temperature motions of atmosphere molecules (typically 3 cm wavelength), 2) decimetric (3-70 cm) from gyrations of electrons around lines of force in the planet's field, 3) decametric (up to tens of meters wavelength) huge bursts of radio noise like lightning flashes. Decametric bursts have the power of several hydrogen bombs, with an average peak value 10,000 times that of the decimetric signals. The Pioneers have now confirmed electron motions as the source of the decimetric signals. The major mystery, however, was the enormous decametric bursts.

It has been theorized that Io is conductive enough to link up magnetic lines of force to Jupiter's ionosphere, allowing a huge current flow from one point on the ionosphere up to Io, across the moon's 3,640 km (2,260 mi.) diameter and back down to a second point on the ionosphere reached by field lines on the other side of Io (see diagram). Pioneer measurements show that Io's ionosphere appears to be of sufficient extent and conductivity for the big moon to close this current circuit without dissipating too much energy. This massive current flow may also produce enormous lightning bolts on Io.

The energetic particle experiments of both Dr. Walker Filius, UC, San Diego, and Dr. James Van Allen, U. of Iowa, measured very high electron flow near Io's "flux tube" (the sector of Jupiter's magnetic field which passes through Io). In the last ten minutes approaching Io's flux tube, electrons with energy above .46 MeV (but not much above 8 MeV) increased by about ten times. There was no other similar dramatic increase of this type within the magnetosphere.

Exact location in the circuit of the 400 kv electrical potential to drive these huge current flows is not known. The locations are either between the top of Io's high ionosphere and the surface of the moon, or between points in Jupiter's ionosphere.

3. The outer magnetosphere lies between 30 and 45 Jupiter diameters 4,320,000 and 6,400,000 km (2,700,000 and 4,000,000 mi.) from the planet. Due to buffeting by the solar wind and weakening of all the planet-based forces, both particles and fields tend to be irregular and mixed up in this outer region. Particles here often have relatively high energies, and mirror back and forth between north and south poles just as they do in the inner and middle magnetospheres.

Despite Jupiter's high-speed spin, its magnetic field spirals back relatively little. The magnetosphere, like the Earth's, has a magnetic tail which streams away from the Sun, out beyond the orbit of Saturn, almost three quarters of a billion km (half-a-billion mi.)

As the Pioneer spacecraft approached Jupiter, bursts of electrons traveling near the speed of light and lasting for several days were observed with increasing frequency and intensity in interplanetary space. When analyzed in detail, the intensity and energy of the electrons were found to vary with the ten hour period of Jupiter's rotation, proving that the electrons escaped from Jupiter's magnetosphere, even though the electrons were over 320 million km (200 million mi.) from the planet. A careful examination of data from Earth-orbiting satellites and other spacecraft has shown the presence of electrons from Jupiter even as far in as the orbit of Mercury. Scientists do not now understand how such great numbers of electrons are accelerated or how they escape from Jupiter. To maintain the observed intensities requires a power input of more than 100 billion watts, says Dr. Simpson, University of Chicago.

Occasionally near the planet, bursts of low energy protons are observed escaping from Jupiter's magnetosphere.

JUPITER'S RADIO SIGNALS

The Pioneers appear to have found the source of Jupiter's massive radio bursts by measuring the electric current flow created when the moon Io "closes switch" to send Jupiter's massive radio bursts.

Motion of Io through Jupiter's magnetic field is believed to set up an electrical potential of 400 kilo volts across the satellite (see drawing next page) which drives these huge current flows. Current moves across the top of Io's high ionosphere.

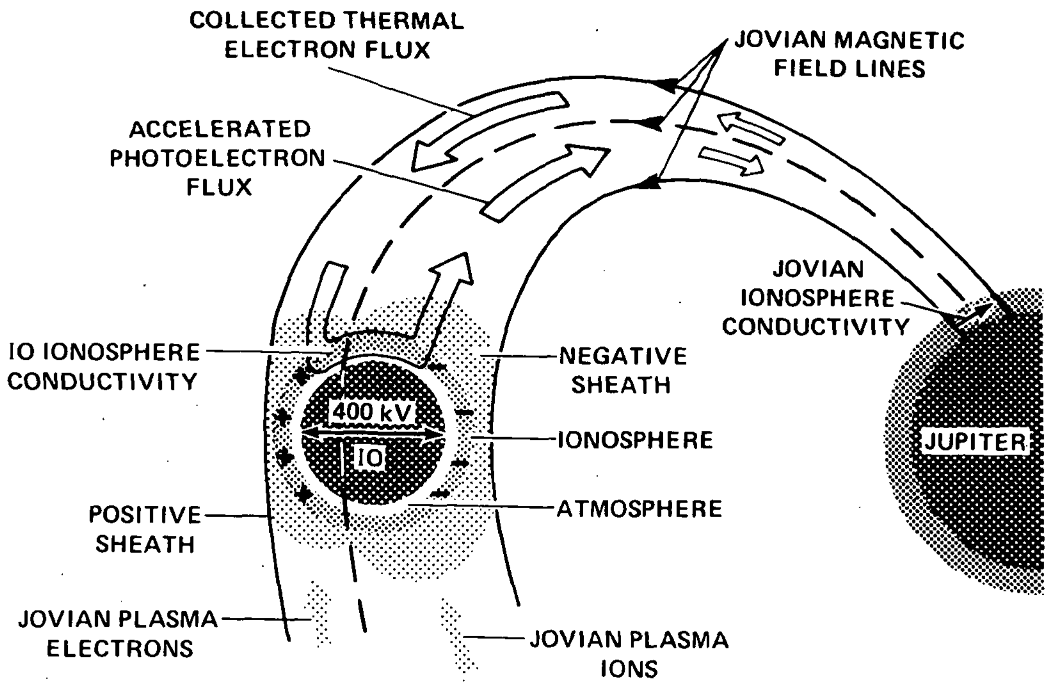
Some scientists have also proposed an electrical potential between points in Jupiter's ionosphere.

Estimated power carried through Io's flux tube is 10,000 000,000,000 watts.

Detective work to identify Io as the source of Jupiter's decametric radio blasts has involved several facts, according to Dr. David Morrison, University of Hawaii. The radio bursts occur roughly every 21 hours (half of Io's orbit period). This seemed to mean that Io had to be on one side or the other of Jupiter to get a radio burst. But also for a burst, one of three places on Jupiter's visible surface had to be facing the Earth. Since this combination seemed present every time, Io was a strong suspect.

Huge amounts of sodium ions have been measured from Earth in Io's ionosphere and around its orbit. The sodium ions seem to provide a highly conductive medium to close the circuit at Io, according to Dr. Morrison. They are produced at a rate of 100 million atoms per second per square inch, and are believed to be chipped (sputtered) off the salt-plain surface of the big moon by impacts of high-velocity atomic nuclei from Jupiter's radiation belts.

THE MOON IO IS SOURCE OF JUPITER'S MASSIVE RADIO BURSTS



JUPITER IS THE STRONGEST RADIO SOURCE in the sky except the Sun. Enormous radio blasts come from electric current flows of 10,000,000,000,000 Watts power, when the moon, Io, "closes the switch." By moving through Jupiter's magnetic field, Io's ionosphere is charged positively on one side, negatively on the other. This produces an electrical potential of 400 kilovolts across the satellite. When Io reaches the right position, current flows along magnetic field lines down to Jupiter's electrically conductive ionosphere, and back to Io. This completes the circuit, and produces tremendous radio noise. Two Pioneer 11 experiments measured this current flow.

FORMATION OF THE PLANET JUPITER

The cloud of gas which formed Jupiter gave birth to the giant planet, in large part, during a 70,000-year convulsive contraction, followed by a headlong collapse to form the planet in an incredibly brief three months.

Pioneer measurements of the internal heat emitted by Jupiter, the properties of its moons, and other characteristics have allowed the first detailed calculations of the planet's formation process.

Jupiter's history is something like that for youth and age of a small star, with no mature phase in between. Jupiter has only 1/70th of the mass required to fuel the "burning", or nuclear fusion, stage of a long-lived star. So the planet went from an original gas cloud to a body rapidly heated "red hot" by contraction with temperatures of about 50,000 degrees C. (90,000 degrees F.) at the center and 1,500 degrees C (27,000 degrees F.) at the top of the atmosphere (compared with today's -150 degrees C (-270 degrees F.) at the cloudtops). Jupiter began a 4.5 billion year cooling process, which is still going on. In this phase, it is like a small, cooling "white dwarf" star. Jupiter's internal temperatures are still high enough, 30,000 degrees C (54,000 degrees F.) at the center, to make it a liquid planet.

Dr. James Pollack, Ames Center, calculates that when it failed as a star, Jupiter continued to contract and radiate heat, as it has ever since. Today about 75 per cent of the heat coming from Jupiter's interior, he estimates, is left from heat of collapse; the other 25 per cent is generated by continuing contraction of the intensely compressed gas making up the planet.

Jupiter, as we know it, appears to have begun to form about 4.5 billion years ago, about the same time as the Earth--from a flat rotating cloud of convecting gas of solar composition, which either condensed into a relatively uniform body with the same mixture of elements as the Sun--or collapsed onto an existing rocky core to form the planet.

In just a few million years, scientists think, Jupiter's primordial gas cloud began to take shape with the beginning of the gravitational contraction of an outer part of the rotating cloud of matter which formed the Sun. This first proto-Jupiter was a very diffuse rotating cloud, then some 600 million miles in diameter. The cloud also contained small grains of heavier material (dust). These grains had either condensed earlier or formed as the cloud rotated and eddied, and were well mixed with Jupiter's gases.

After this first contraction, in less than a million more years, the cloud had decreased to about 400 million miles in diameter. This was dense enough for the molecules orbiting the cloud's center to interact with each other, forming a gas cloud in hydrostatic equilibrium.

At this point, things went fast. From a diameter of about 400 million miles, scientists calculate that the proto-planet quickly shrank to near its present diameter.

The cloud, like the sun, was composed by numbers of atoms of 93 per cent hydrogen, 6 per cent helium and 1 per cent all other elements. It was only about 55 degrees C. (100 degrees F.) above absolute zero. During the first phase of fast contraction, the cloud diameter shrank some 32 to 16 million kilometers (20 to 10 million miles) in just 70,000 years, and the temperature rose to about 2,210 degrees C. (4,000 degrees F.). At this point, the hydrogen began to ionize and dissociate, and the proto-planet "flared" up.

It then shrank in just three months in a headlong hydrodynamic collapse to only about 640,000 km (400,000 mi.) in diameter, about four or five times the size of today's Jupiter.

In the 100,000 years after flare-up, the early Jupiter behaved like a pre-main-sequence star, generating massive amounts of heat by gravitational contraction. This was enough heat to turn the planet red hot, during formation of the moons and heat the interior to 50,000 degrees C. (90,000 degrees F.). Seen from the inner moon Io, Jupiter would have filled a third of the sky--a glowing dull-red giant.

After this 100,000-year hottest period, further contraction took place much more slowly, and the interior began to cool. At that point, Jupiter was radiating energy like a cooling white dwarf star.

From this point also, changes were all very slow. The planet began the process which goes on today--four and a half billion years of contraction and heat radiation.

If Jupiter has a rocky core, the formation process was slightly different. In this case, the heavy dust grains in the condensing Jupiter cloud would have been slowed by drag of the lighter gasses. The grains would have collided and then stuck together by gravitation attraction. These larger grains, up to 2.5 cm (1 in.) in diameter, then formed into a flat central plane in the cloud and later became a central rocky sphere of about 30 Earth masses. This would have occurred before gravitational condensation of the lighter elements, which then would have collapsed onto the central rocky core.

Assuming such a core, Jupiter today should have proportionately five times as much heavy material as the Sun. Without the core, composition would be about the same as the Sun.

Jupiter's planet-sized moons certainly contain much heavy material. Both the moons and the core, if it exists, are mostly ices (largely water ice) and rocks, made of silicon, iron, magnesium and oxygen.

If Jupiter has a substantial core, the heating of the planet by contraction probably forced the water out of the core into the rest of the planet, including perhaps its atmosphere. This might give Jupiter some extra water clouds. (See Jupiter weather section.)

Because the original Jupiter cloud was a flattened rotating disc, the four plant-sized inner satellites: Io, Europa, Ganymede and Callisto, formed from the heavy materials in the disc.

The best direct evidence for Jupiter's history is the regular density gradient and composition of the moons. The Pioneers found that Io and Europa, the two closest big moons, have densities a little more and a little less, respectively, than that of the Earth's moon, while the outer two moons appear to be about half water ice. Most scientists believe that during its long-lasting "red hot" phase, Jupiter kept the two inner moons too hot for water to condense for millions of years. Farther out at the distance of the two outer moons, much water did condense. Perhaps a million years later, after Jupiter's formation, the Sun also at the end of its formation cycle, sent out massive solar wind streams during its "T-Tauri phase". This big solar wind swept the remaining uncondensed lighter elements surrounding both Jupiter, its moons, (and the other planets) out of the solar system altogether.

The process left two rocky inner moons and two icy outer ones. The range of densities for the moons going out from the planet, 3.5, 3.1, 2.0 and 1.5 grams (.49, .11, .07 and .05 oz.) per cc (6.25 cu in.) is just what it should be for a massive long-lasting early flow of heat radiation from Jupiter.

These brief, proto-star-like phases calculated for both Jupiter and Saturn means there have been two different periods of relatively high temperatures in the outer solar system.

- more -

THE MOONS OF JUPITER

The gleaming white-and-orange salt plains of Io, the snow craters and maria of the ice and water moon, Ganymede, and numerous other discoveries about Jupiter's four planet-sized Galilean satellites (two inner rock moons and two outer ice or water moons) have come from Earth-based and Pioneer data. Jupiter has 12 or possibly 13 moons, but the four large Galilean satellites are the scientifically most interesting.

Ganymede may be a planet-Mercury-sized drop of water with an icy outer crust. Muddy-looking, outermost Callisto appears made of the primordial stuff of Jupiter, with little change since formation; and Europa, with relatively little water in total, still appears to be sheathed in ice--like a snowball with a rock inside.

Io switches on Jupiter's radio signals, and makes enough sodium to fill its orbit and surround Jupiter.

Jupiter's big moons on the average are as large as Mercury. Ganymede and Callisto are larger than Mercury, and all four would be visible to the naked eye. They range down in density and vary in composition because of the differences in the heating they received from Jupiter's early proto-star-like, high-heating phase. Effect of this heating when the forming moons were dense disc surrounding Jupiter is that lighter elements (including water) with low vaporization temperatures were able to condense only in the cooler outer moons, while heavier elements with higher vaporization temperatures were able to condense in the two hotter inner ones. Io, for example, was above the condensation point of water for five to ten million years during this formation process. All the lighter elements which didn't condense out into moons are believed to have been swept out of the solar system completely by the massive blasts of solar wind during the T-Tauri phase of the Sun's formation.

Today the surfaces of all four moons are frozen rock solid by the cold of space with average daylight surface temperatures of -145 degrees C (-230 degrees F.). Because of strong tides produced in Jupiter's moons by the giant planet's gravity, all four of the big moons are locked with the same face always to the planet. This is also true of Earth's moon.

- more -

In general, the Galilean moons appear to be composed of water ice, water, and silicates. Other ices such as methane and ammonia would have been difficult to condense on the moons because they have much lower condensation temperatures, and would have been swept away by blasts of "T-Tauri" phase solar wind.

The rocky moons are believed to contain enough of such radioactive elements as uranium, thorium and potassium to cause melting and partial differentiation of their interiors. All four moons are inside Jupiter's magnetosphere and constantly exposed to high-energy particle bombardment.

Leading hemispheres of the moons often differ in color and composition from trailing hemispheres, apparently because they are more exposed to high velocity ionized particles, and to the heavy concentrations (170 times Earth's) of meteroids at Jupiter.

Io

Named after a Greek maiden pursued by Jupiter, Io is the most reflective known object in the solar system. It has a distinct orange color, some atmosphere, and is denser than Earth's moon. Pioneer found Io 23 per cent denser than previously believed.

Scientists now attribute Io's brilliance to salts of sodium and potassium, and to sulfates. These materials were dissolved out and deposited on Io's surface when the heat of radioactivity of its rocks and tidal motions within the moon, building up over a billion or more years, melted, forced to the surface, and evaporated most of the water bound in its rocks. Io's surface is almost certainly cratered and has huge plains of white crystals, like dried-up oceans or the Utah salt flats. These salt plains cover much of a body almost the size of the planet Mercury.

Io's high reflectivity tells a good deal about the satellite, says Dr. David Morrison, University of Hawaii. It reflects more than 60 per cent of the sunlight it receives, compared with 17 per cent reflected by the Moon and 40 per cent by the whitest rocks. Io is as reflective in infrared light as in visible light, a quality it shares with a few materials, among them the surface of the Utah salt flats and with certain sulfates.

Io's surface must be dusty and porous because infrared measurements show it heats fast in sunlight and cools fast in Jupiter's shadow. It behaves something like a commercial insulating material.

The first close-up photo ever taken of Io, (by Pioneer 11) shows extensive white and orange-brown areas, with less variation than the surfaces of the other moons. The Pioneer picture does not show dark polar caps apparently there in pictures from Earth. The orange-brown areas are believed to result from radiation effects on surface materials

Spectroscopic measurements from Earth have shown a cloud of sodium vapor extending 16,000 km (10,000 mi.) from the moon's surface. The sodium appears to be sputtered off Io's surface by the bombardment of the high-velocity protons and other atomic nuclei from Jupiter's intense radiation belts. Similar observations suggest that sulfur and potassium are also sputtered from Io.

The orange patches on Io may be due to bombardment by protons of salts of these elements on its surface. Like Earth's moon, Io is believed to have differentiated substantially with lighter materials near the surface and heaviest in the center, due to heating from the radioactivity of its rocks (mostly partially hydrated silicates) over the past four billion years.

As the closest-in of Jupiter's big moons, 420,000 km (260,000 mi.), Io absorbs huge amounts of high energy particles from the most intense part of Jupiter's radiation belts. Without the sweeping action mainly by Io, as well as the other four moons within the magnetosphere, Jupiter's radiation belts would be 100 times more intense.

The Pioneers found that by absorbing high energy protons (hydrogen nuclei) from the belts and giving them an electron from its ionosphere, Io has generated a cloud of neutral hydrogen 161,000 km (100,000 mi.) thick and 805,000 km (500,000 mi.) long, extending a third of the way around its orbit. There appears to be only 1/1000th as many hydrogen atoms as sodium ions around Io.

Pioneer also found that Io's atmosphere is 20,000 times less dense than Earth's, and extends 115 km (70 mi.) above the surface.

Io has an ionosphere 700 km (420 mi.) high on the day side, with the upper layers on the night side swept away by Jupiter's magnetic field. Io is unique in that its ionosphere is inside the magnetosphere of another body (Jupiter). Ionosphere density is 60,000 electrons per cc (.064 cu. in.) on the day side and 9,000 per cc (.064 cu. in.) on the night side. Io's ionosphere's density and extent suggest an unusual gas mixture, hydrogen, sodium and possibly nitrogen.

Europa

Europa, also pursued by Jupiter in mythology, is almost as rocky as Io, with a density 3.28 times that of water and almost as bright. Europa is 670,000 km (415,000 mi.) from Jupiter. A long-distance Pioneer 10 picture of poor resolution (the only one existing) shows dark features in the northern hemisphere, perhaps large basins as on Earth's moon, and a large, very bright region in the southern hemisphere. Water ice has been found extensively in measurements from the Earth. Though Europa has relatively little water, most of what it has appears to have been melted and forced to the surface by radioactive heating of its interior over a billion years or more. Scientists doubt that Europa's sister-moon, Io, ever had any free water because it formed in hotter conditions. But Europa is thought to have had perhaps 10 per cent free water, not bound to its silicates (rocks), and like Io, to be largely differentiated. Over the past four billion years, radioactivity in the rocks is believed to have heated Europa so that the water rose to the surface and froze in a layer perhaps 50 km (30 mi.) thick lying 10 km (6 mi.) below the surface. The major asteroid impacts (like that forming the Mare Imbrium on the Moon) are believed to have knocked off the top layer of rocks exposing the ice layer underneath.

Ganymede

Jupiter's third big moon, Ganymede, is 10 per cent larger in diameter than the planet Mercury, and is a million km (665,000 mi.) from Jupiter, a little over twice as far out as Io. Surface gravity on this huge outer ice and water moon is 15 per cent of Earth gravity. According to calculations by Dr. John Lewis, MIT, bacause of radioactive heating, Ganymede may be mostly liquid water, a planet-sized drop of water with a core of mud and a crust of ice.

Pioneer pictures show much more surface variation than on Io. Features look somewhat similar to those on Earth's moon. There seems to be a north polar mare, and a central mare 1,200 km (800 mi.) in diameter, plus numerous other large features and a bright southern region. There are also some extremely dark spots and one very bright feature which some have theorized might be a huge ice peak.

Earth spectroscopic measurements indicate that Ganymede's surface has large areas of water frost, though these are smaller than the areas on Europa. Eclipse observations suggest that the upper half inch of its surface is fine grained. Recent radar measurements from Earth suggest that the surface may consist of fairly large blocks of rock embedded in ice.

Taking this and other Pioneer evidence, scientists believe that there is enough rock in Ganymede for radioactive interior heating with substantial melting and movement of water toward the surface. This would provide a liquid or ice interior, an icy surface and a frost layer.

Ganymede may have a very thin atmosphere. Among proposed atmosphere constituents are methane and ammonia.

Callisto

Jupiter's outer big moon, Callisto, another nymph chased by Jupiter, probably comes closest to being unchanged 4.5 billion years after formation. This moon has the darkest surface. Orbiting far out at 1,800,000 km (1,170,000 mi.) from Jupiter, Callisto was cool enough even during Jupiter's high heat phase for the lighter elements to condense there and form it. More than half water, Callisto hasn't enough rock for complete differentiation by radioactive heating. Hence less complete melting and differentiation of elements by weight has taken place in the moon's interior and Callisto's surface and interior are the same mixture of ice, dust, rock and debris that formed originally from the center of the cloud that condensed to become Jupiter. Earth measurements show no water on Callisto because there was no radioactive heating and hence no flow of water to the surface from the interior.

Jupiter's Galilean Moons (Pioneer Measurements)

	Lunar Masses	Density (gm/cc)	Density (oz./cu. in.)	Diameter (km)	Diameter (mi.)
Io	1.22	3.52	.123	3640	2180
Europa	.67	3.28	.115	3050	1830
Ganymede	2.02	1.95	.068	5270	3160
Callisto	1.47	1.63	.057	5000	3000

	Distance from Planet
Io	421,400 km (261,900 mi.)
Europa	670,500 km (416,600 mi.)
Ganymede	1,069,000 km (665,000 mi.)
Callisto	1,881,200 km (1,169,000 mi.)

Average daylight surface temperature, all four moons
-145 degrees C (-230 degrees F.)

- more -

PIONEERS SURVEY INTERPLANETARY SPACE TO BEYOND SATURN

Unexpectedly, they have found that solar wind turbulence blocks out low energy cosmic rays for the entire distance. Scientists had expected a five-time increase in low energy cosmic ray particles by Saturn's orbit, even as close in as Jupiter. These particles are important for understanding the galaxy.

In the entire region of interplanetary space bounded by Saturn's orbit, as expected, the strength of the Sun's magnetic field, the density of the solar wind and numbers of solar high energy particles all decline roughly as the square of the distance from the Sun. Because of solar wind turbulence, temperature of the solar wind has unexpectedly remained high out to the orbit of Saturn.

Pioneer 11, en route between Jupiter and Saturn, is now about 57.8 million km (93 million mi.) above the plane containing the Earth and the other planets and so far has seen no major unexpected phenomena in this sector of the solar atmosphere.

Scientists hope soon to get out of the region of blockage of low-energy galactic cosmic ray particles so that they can measure totals of all galactic cosmic rays in the solar system. This will allow estimates of total cosmic ray energy vs. light energy in the galaxy. Current calculations suggest that there is a far higher proportion of cosmic rays in interstellar space than would be produced by stars, if the Sun is a typical star. This either means that the Sun is unique in producing far more light than cosmic ray particles or, more likely, that large numbers of cosmic ray particles, produced by supernovas, (or perhaps in the dense mass of stars at the galactic center) are trapped in our part of the galaxy. A further explanation is that supernovas have blown channels through the interstellar gas and magnetic fields, and that the galactic cosmic rays (fast-traveling nuclei of atoms) move through these channels. This would account for the apparent high local intensities near the Earth.

Scientists are hopeful that Pioneer 11 may penetrate into interstellar space and measure it directly. The solar magnetic field is believed to make a magnetic cavity in the "interstellar wind" (ionized particles blowing between the stars) much like the magnetic envelopes around the Earth and Jupiter. This solar envelope is called the heliosphere, and may have a bow shock wave in the interstellar wind medium much as do the magnetospheres of the Earth and Jupiter within the solar wind.

With the planned targeting for the Saturn flyby in 1979, Pioneer 11 will leave Saturn headed for this bow shock of the heliosphere. Since the interstellar medium is believed to push back the heliosphere boundary toward the Sun at the shock front, Pioneer 11 may cross this boundary before it reaches limits of communication distance near the orbit of Uranus, 3.2 billion km (2 billion mi.) from the Sun. If so it may cross into interstellar space. The Sun will be in the quiet period then, and this should make the shock front closer in and a crossing more likely.

The heliosphere also is believed to have a "tail" opposite the bow shock wave, as do the planet magnetospheres.

Pioneer 10 is moving out into this stretched-out tail and probably will not penetrate into interstellar space before contact with it is lost.

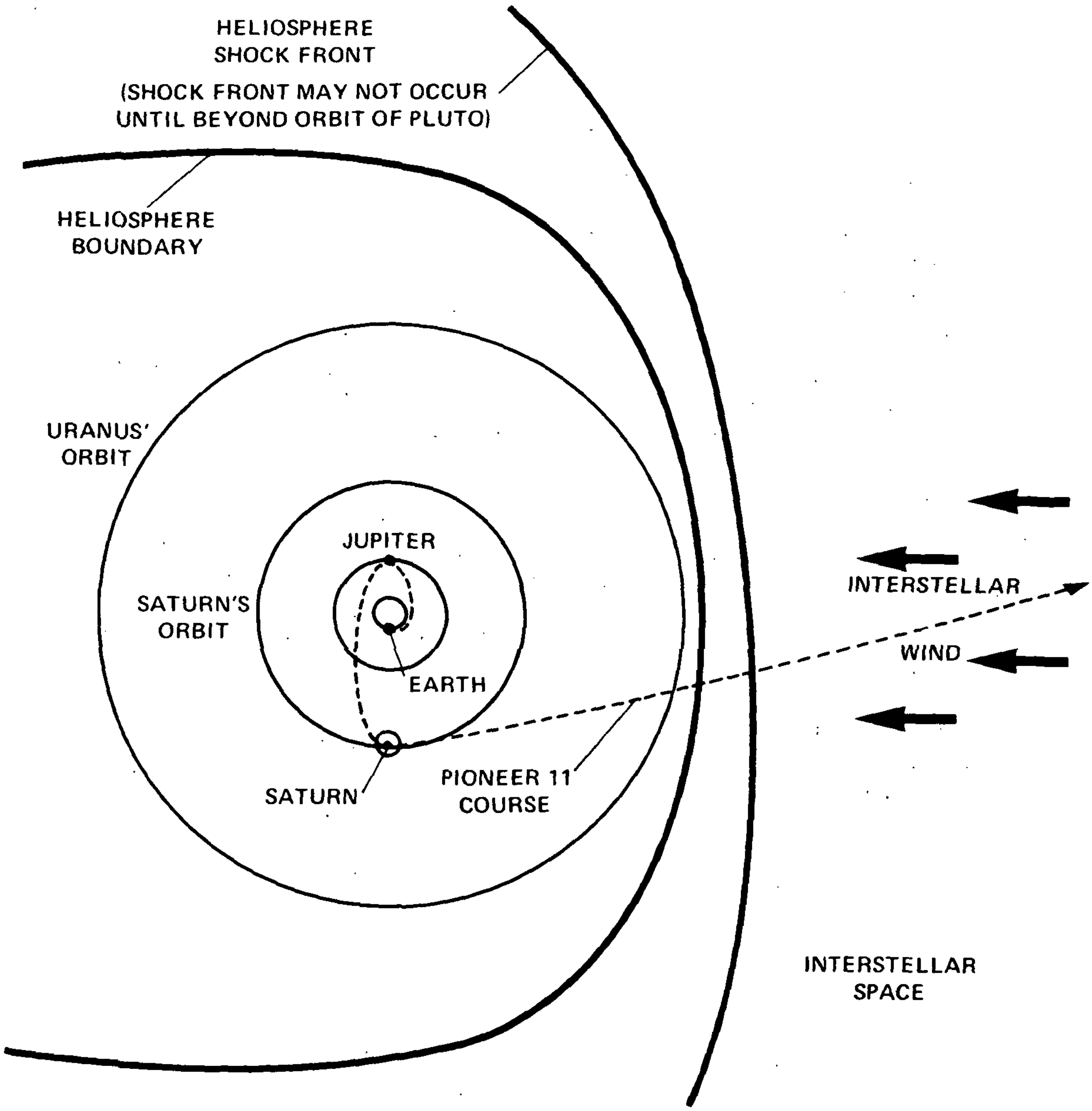
Though spacecraft signals become fainter with distance, both Pioneers should return data out to Uranus' orbit, and perhaps beyond. This far-tracking over 3.2 billion km (2 billion mi.) may eventually have to be done by the huge radiotelescope at Arecibo, Puerto Rico. Because of declines in spacecraft power with time and distance, instruments may have to be run one at a time at the fringes of possible communications.

The Pioneers also have measured changes in the ratios of oxygen to nitrogen to carbon among the low-energy cosmic ray particles seen. These were measured by the instrument of Dr. Frank McDonald, Goddard Space Flight Center.

These changes in ratio now have been attributed to differences in ionization potential of these elements by solar ultraviolet. As neutral atoms of oxygen, carbon and nitrogen diffuse into the heliosphere from interstellar space, they lose an electron at different rates and are then accelerated by solar wind turbulence, becoming low energy cosmic rays.

Experimenters also find that beyond Saturn, the Sun's magnetic field (which guides high-energy particles out from the Sun) is wound up tightly around the Sun, almost like a phonograph record. In addition, the field is so snarled by turbulence that surges of high energy particles can no longer be tied to events on the Sun as they can as far out as Jupiter. However, even beyond Saturn, the solar wind still shows effects of events on the Sun.

PIONEER 11 MAY REACH INTERSTELLAR WIND



Other Pioneer interplanetary discoveries include the following:

Neutral hydrogen and helium from the interstellar medium flows into the heliosphere as the solar system moves through interstellar space at around 70,000 kmph (45,000 mph). Both Pioneers have identified these gases. For unexplained reasons, this nuetral gas streams into the solar system along the plane of the orbits of the planets and of the Sun's rotation. This entry point is 60 degrees away from the direction of travel of the solar system through interstellar space and hence 60 degrees away from the direction from which the particles should come.

Pioneer ultraviolet instruments have been able to separate both interstellar neutral hydrogen and helium from the gases originating in the Sun.

Neither the zodiacal light (the faint glow seen in the night sky from Earth along the zodiac) nor the Gegenschein, a similar glow directly opposite the Sun, are due to reflection of sunlight from concentrations of dust near the Earth, nor in the Asteroid Belt. Instead they are due to sunlight reflection from evenly-distributed interplanetary dust. Amounts of dust decline going away from the Sun as the square of the distance out to the far side of the Asteroid Belt, about 480 million km (300 million mi.) from the Sun.

Beyond the Asteroid Belt, this decline reaches a point at which interplanetary dust virtually disappears.

Hence, beyond the Belt, experimenters measured the integrated starlight from the Galaxy, making possible such measurements as the comparison of cosmic ray energy versus light energy from the stars, already mentioned.

As reported at the time of passage of the Belt, the Pioneers found no swarms of 48,000 mph (30,000 mph) dust and sand particles expected by some scientists, in the Asteroid Belt, despite the numbers of larger bodies in the Belt. The Belt appears to present no hazard to spacecraft passing through it. The Pioneers also found a clear, dust-free gap between 1.14 and 1.34 Earth distances (AU) from the Sun. This clear belt seems to be swept free of dust by the gravity of the Earth and Mars.

Turbulence of the solar wind occurs for the following reasons:

As it blows out from the Sun, the solar wind does not expand symmetrically with regular decreases in temperature as expected.

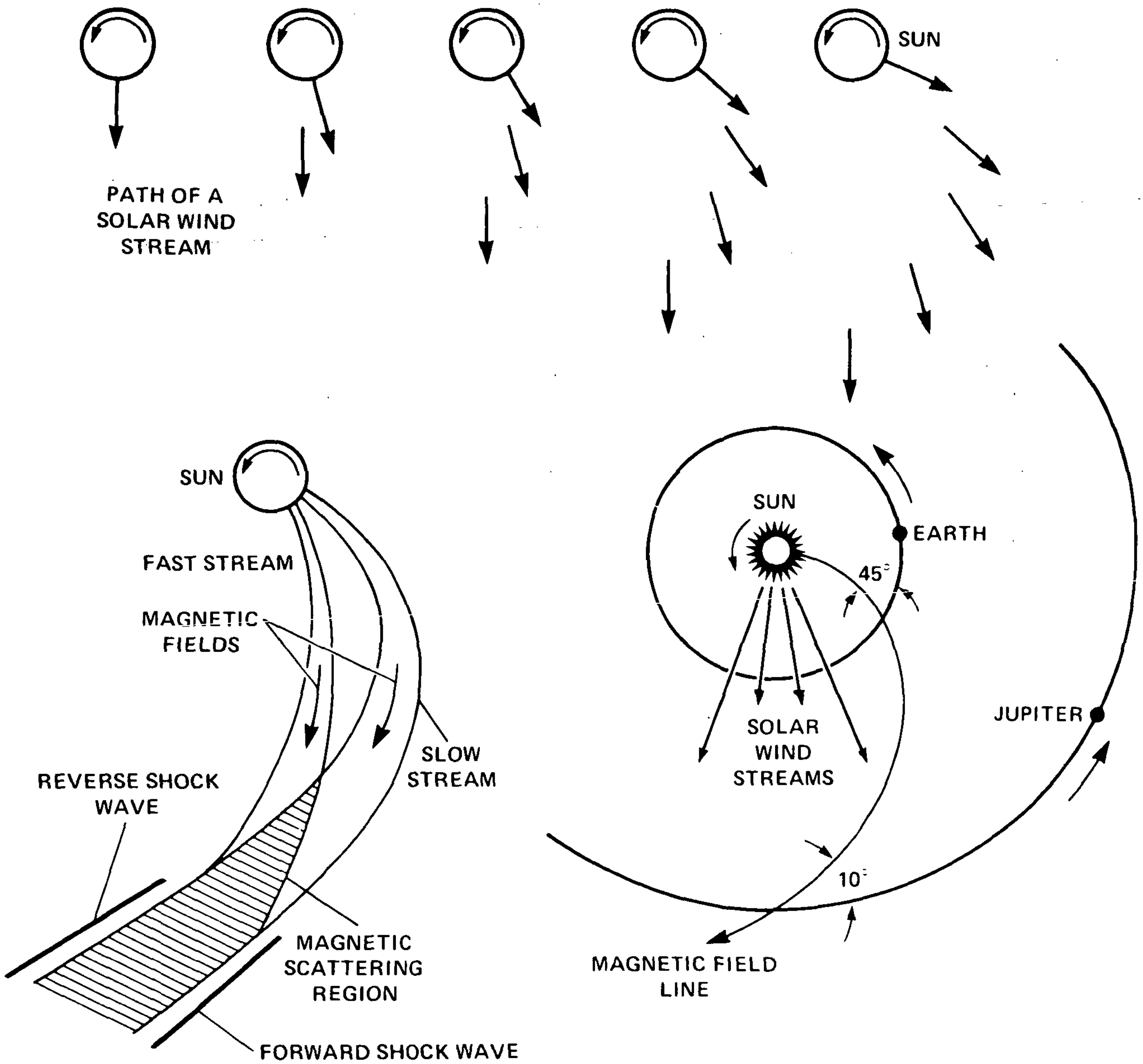
- more -

The solar corona apparently contains hot spots and since solar wind speeds depend on corona temperatures, these produce fast and slow solar wind streams. Bumping together of fast and slow streams moving out from the rotating Sun produces higher-than-expected temperatures and also steep gradients in the magnetic fields carried by the solar wind.

These magnetic interfaces between solar wind streams scatter the lower energy (less than 100 MeV) cosmic ray particles coming in from the Galaxy. As a result, there are very few low-energy cosmic rays inside Saturn's orbit. This cosmic ray blocking effect may last out to 20 or 30 Earth distances (AU) from the Sun. This is two to three billion miles out from the Sun, out to the orbits of Uranus and Neptune respectively.

-more-

SOLAR WIND TURBULENCE BLOCKS OUT COSMIC RAYS



FAST STREAMS OF SOLAR WIND catch up with slow streams and produce scattering regions (solar wind/magnetic interaction regions) which prevent low energy cosmic rays from penetrating into the Solar System. Turbulent fields flip the particles back out before they can penetrate far. Pioneers 10 and 11 may reach the boundary where this scattering effect ends and galactic cosmic rays increase in numbers. This would allow estimates of total cosmic rays in the Galaxy.

THE POSSIBILITY OF LIFE IN JUPITER'S ATMOSPHERE

The possibility of life in Jupiter's atmosphere continues since Jupiter is largely a liquid planet and its liquid regions are too hot for life, any living organisms would have to be found in its gaseous atmosphere. Between the temperatures for freezing and boiling of water, atmospheric pressure increases with depth from five times Earth's atmospheric pressure to ten times Earth pressure. Life probably would have to begin in this environment.

Pioneer findings suggest upward eddy diffusion of the atmosphere, along with its downward circulation--plus slow atmosphere turnover times of months or years in the equatorial and temperate zones. These conditions could allow atmosphere-borne life to survive, says Dr. Cyril Ponnamperuma, University of Maryland. Such life would survive by the known ability of microorganisms to reproduce in enormous numbers in just hours or days--with part of the population constantly shunted upward to liveable regions.

However, say Drs. Ponnamperuma and Sherwood Chang of NASA's Ames Research Center, the principal question is: Could life have begun in the first place on Jupiter--during the giant planet's four and a half billion year history?

Here the two main negative factors are: that the very large amounts of hydrogen on Jupiter may lower concentrations of the building blocks of life (complex organic molecules). And once formed, these molecules are likely to be destroyed by atmospheric circulation to hot levels.

The main positive factors for generation of life are the huge amounts of raw materials available to make life building blocks (ammonia, methane, and water) and large amounts of energy--plus the enormous numbers of particles, both liquid and solid, in Jupiter's clouds and atmosphere. Such particles might provide tiny protected sites for concentration and interaction of complex organic molecules in the surrounding sea of Jovian hydrogen.

Jupiter has 1,000 times as large a region as the Earth for formation of complex organic molecules. Numerous experiments on Earth with partially simulated Jupiter environments have shown that energy applied to a Jupiter atmosphere of ammonia, methane and water produces the building blocks of life. However, because of the abundant hydrogen, these complex molecules may well be too few for chemical evolution of life by combination of these life molecules.

The appearance of life on Jupiter, says Dr. Chang, would require mechanisms for concentrating the probably thinly-dispersed organic molecules, and for providing long time periods during which they would be protected from destruction. They also would require a liquid water medium in which to interact and combine.

Whether such a stagnant, water-containing atmopsheric region at Earth-like temperatures exists in Jupiter's vigorously-circulating atmosphere is unknown. However, on as large a planet as Jupiter, a very wide variety of environments may exist, says Dr. Ponnamperuma.

Most doubts about life on Jupiter have been based on the idea that thousands or millions of years are needed to develop highly-complex life-building-block molecules and combine them into a far more complex molecule that could reproduce itself. On this idea, if they were formed, complex organic molecules would be destroyed by heat on Jupiter before life could appear.

On the other hand, says Dr. Ponnamperuma, destruction times for complex molecules such as amino acids may have been only years or decades on the primitive Earth when life appeared. Origin of life on a planet, he says, may well depend less on huge time periods, than on the number of times nature mixes up the proper ingredients and "shakes them up" in the right microenvironment. Enough billions or trillions of attempts could produce a very complex molecule able to replicate itself.

Breakdown of atmospheric methane by ultraviolet light produces the low concentrations of ethan and some acetylene measured in Jupiter's stratosphere. Similar processes acting on atmospheric gases probably produce small amounts of other simple organic molecules as well. Ultraviolet light probably also produces reddish molecules made of linked sulfur atoms. Many scientists believe the red color is due to a combination of colored organics and linked sulfur molecules.

Circulation of Jupiter's stratosphere may take about 1,000 years, says Dr. Ponnamperuma. If this colored material is found in the atmosphere, it could accumulate there, and eventually drift down into the fast-circulating lower atmosphere, where it would be sucked farther down to hot levels and destroyed.

If atmosphere turnover takes months, enough of the red material would be produced by available ultraviolet light to account for the red clouds.

Given fast circulation, ultraviolet photochemistry may not produce enough material to account for the clouds from either polymeric sulfur or complex organics. If this is the case, the colored material might be produced by visible light. The only mechanisms known for using this longer wavelength light are biological.

Calculations show that photosynthetic Jupiter organisms in the lower atmosphere, if any exist, could produce sufficient red coloring to account for the clouds--even with high atmosphere circulation rates.

Because microscopic organisms (at least on Earth) have very short reproduction and growth times, microorganisms might be produced in countless numbers, as on Earth, and thrown upward as well as sucked down by turbulent atmosphere circulation.

Given a large enough supply of food and energy on Jupiter, enough organisms might reproduce to constantly replace organisms sucked down to destruction in hot lower atmosphere levels.

Because certain environments, such as the surfaces of minute aerosols in Jupiter's atmosphere may provide hospitable sites for life, a problem exists even if there is no life on Jupiter. This is the possibility of contamination of the Jupiter environment by Earth organisms, riding aboard the atmosphere probes planned by NASA, and perhaps other countries.

Even if life is present on the giant planet, it could be contaminated by newly-arrived microorganisms from Earth. For future missions, NASA has planetary quarantine programs aimed at handling both problems.

-more-

DUST

While Pioneer found very little dust in the Asteroid Belt, Jupiter, by contrast, seems to act as a giant vacuum cleaner, constantly sucking in small particles from a very large region of space.

The Pioneers found that there are about 170 times as many meteoroids striking Jupiter's atmosphere as strike the Earth for same-sized areas. This amounts to six ergs of energy per square cm per second. This is enough energy to be one source of heat for the upper atmosphere. It is also one source of aerosols in the upper atmosphere. Concentrations of these particles at Jupiter are, of course, due to the planet's large gravity field.

JUPITER'S IONOSPHERE

The Pioneer data show that Jupiter's ionosphere has at least five well-defined layers of differing electron density, and there may be as many as seven layers. The second layer from the top is especially pronounced, and may have been produced by extreme solar ultraviolet radiation.

Jupiter's multilayered ionosphere rises more than 3,000 km (1,800 miles) above the one millibar pressure level at the top of the planet's atmosphere. It is about five times higher and five times hotter than had been predicted. The ionosphere's unexpected depth is believed to be due to the diffusion of its ionized gas by high temperatures. The topside electron-ion temperature is about 600 degrees C. (1,100 degrees F.). The heat is believed to be produced by impacts of high energy particles from the radiation belts, hydromagnetic waves from Jupiter's magnetosphere, gravity waves from the lower atmosphere, and solar ultraviolet radiation.

The Pioneer measurements may be interpreted in terms of an upper atmosphere consisting of either molecular hydrogen with a temperature of about 600 degrees C. (1,100 degrees F.) or atomic hydrogen with a temperature on the order of 150 degrees C. (280 degrees F.).

There appear to be some difference between the ionosphere in polar latitudes and that in temperate regions.

THE INTERIOR OF JUPITER

Jupiter's intense interior heat has been held inside the planet for some four billion years by the "new metal", metallic hydrogen. This material also accounts for the behaviour of the planet's magnetic field.

Pioneer 10 found that Jupiter is a liquid planet, and is very symmetrical with no gravitational irregularities. This liquid character means that the planet is in hydrostatic equilibrium like a drop of water. By gravity and radio occultation measurements, it looks as smooth as if it had been turned on a lathe. Because of the forces of rapid, ten-hour rotation on its liquid material, Jupiter is somewhat thicker through the equator than the poles. At the .8 of an Earth atmosphere pressure level, Jupiter's polar and equatorial diameters by two measurement methods accurate to 7 km are: polar 135,516 km (81,300 mi.), equatorial, 142,796 km (85,650 mi.). This is ten times as flattened as Earth, Jupiter's overall density is 1-1/3 times that of water.

Direct observations aside, Jupiter's interior is so hot that solid materials cannot survive, and hence it is a liquid planet. Temperature at the center is about 30,000 degrees C. (54,000 degrees F.), six times that at the surface of the Sun. These conditions mean that much of Jupiter's interior must consist of liquid metallic hydrogen.

This liquid metallic hydrogen region is now believed to begin about a quarter of the distance between Jupiter's surface and the planet's center.

Findings about liquid metallic hydrogen, which so far has only been identified inside Jupiter (where enormous temperatures and pressures make it), confirm recent advances in solid-state physics. In addition to its electrical properties, which account for Jupiter's field, this "new metal" is now seen as the simplest of the alkaline metals. (Others are lithium, sodium, and potassium.) The new material has low thermal conductivity and is opaque to radiated energy. This explains how Jupiter has retained its primordial heat for some four billion years, since its heat can neither be radiated nor conducted away, says Dr. William Hubbard, University of Arizona.

Jupiter's magnetic field, like Earth's, is created by an electrical dynamo process in this liquid metal. The dynamo is produced by convection currents in the electrically-conductive liquid metal interior.

Pioneer measurements show that the dynamo process takes place close to the top of the liquid metal region, closer to the surface than the liquid iron core, which makes Earth's field.

This finding agrees with recent work in hydromagnetics, and accounts for the Pioneer measurements of strong quadropole and octopole fields outside the planet, despite the fact that such fields decrease rapidly with distance. Velocity of the currents in this metallic hydrogen is also believed greater than in Earth's core.

Convective, heat-driven circulation is not possible throughout Jupiter because convective flow cannot occur across the boundary between metallic and molecular hydrogen, where density of hydrogen is believed to increase about 25 per cent. Convective circulation appears to occur in each of the two separate regions, mixing each one fairly evenly. Heat is transferred from the metallic to molecular hydrogen regions by conduction across the boundary between them.

Because of its low density and huge mass (318 times the Earth's), Jupiter is known to be made principally of the light elements, hydrogen and helium (99 per cent). The ratio between the two is about 93 per cent to 6 per cent by numbers of atoms as in the Sun.

Going down the 70,000 km (43,000 mi.) from the cloud-tops to the center, the giant planet looks as follows: At the transition zone from gaseous hydrogen to liquid, 1,000 km, (600 mi.) down, temperature is calculated to be 2,000 degrees C. (3,600 degrees F.). At 3,000 km (1,800 miles) down, temperature is 5,500 degrees C. (9,900 degrees F.) and pressure is 90,000 Earth atmospheres. Here the hydrogen is compressed into a liquid a quarter as dense as water. At 25,000 km (15,000 mi.) down, temperature reaches 11,000 degrees C. (19,800 degrees F.) and pressure three million atmospheres. Here liquid molecular hydrogen turns to liquid metallic hydrogen. From here, over the remaining 45,000 km (27,000 mi.) downward, temperature and pressure increase steadily to the 30,000 degrees C. (54,000 degrees F.) temperature and 100 million atmospheres pressure of the center.

Jupiter's central rocky core is now believed to contain 10 to 20 Earth masses, with 225 Earth masses of hydrogen and 75 Earth masses of helium making up most of the rest of the planet.

Most authorities believe that Jupiter's hydrogen and helium are relatively well mixed.

Because the core is relatively small in relation to Jupiter's total mass, the Pioneer gravity measurements were not fine enough to confirm its existence.

Going out from the rocky core, scientists now believe the layer of liquid metallic hydrogen mixed with molecular helium extends about three quarters of the distance to the surface. There metallic hydrogen turns to a mixture of molecular hydrogen and helium. The upper layer probably contains proportionately more helium than the metallic layer.

The pattern of convection in the region of liquid metallic hydrogen is believed to be strongly affected by magnetic-fluid flow interactions, due to generation of Jupiter's magnetic field, but little is known about this.

The magnetic field is believed to have been first created by the massive convective flow of streams of metallic hydrogen through whatever small magnetic field existed originally in Jupiter. This flow of liquid metal channelled by Jupiter's 10-hour rotation then created electric ring currents which in turn created massive magnetic fields of their own. However, at some point, these dynamo-generated magnetic fields act to limit the flow of electric current. This, in turn, limits the total strength of Jupiter's field. Otherwise, the liquid dynamo process would go on and on generating extremely large magnetic fields.

Jupiter's two-pole (north-south) magnetic field is about ten times as strong as Earth's with about 20,000 times the total energy. It is about twice as tilted (11 degrees) to the rotation axis.

The similarities between Earth's and Jupiter's fields appear to confirm existing dynamo theories for planetary fields.

The four and eight-pole components of Jupiter's field account for 20 per cent of its strength. This field pattern provides evidence that Jupiter's internal currents are more turbulent than Earth's currents, and this fits temperature calculations for Jupiter's interior.

Jupiter's magnetic field appears to be created by several ring currents produced by generator-like liquid flows. Pioneer 10 at 210,000 km (131,000 mi.) from the planet found only a simple magnetosphere, thought to be formed by a single generator much like the Earth's. But Pioneer 11, at only 41,000 km (26,000 mi.) out found that Jupiter's interior may contain a large ring current, along with smaller currents, created by smaller eddies.

Other evidence for the complex magnetic field close to the planet and hence complex interior flow is the flow pattern of high energy particles close in, says Pioneer experimenter, Dr. Walker Filius, University of California, San Diego.

May 17, 1976