JUPITER II

A highly magnetized, rotating liquid drop, Jupiter influences the solar system far beyond its visible dimensions

Second of two articles

BY DIETRICK E. THOMSEN

Produced by a magnetic field 17,000 times as strong as the earth's, Jupiter's magnetosphere is a pulsating bag of charged particles a million times the volume of the earth's magnetosphere. The axis of the field is inclined 11° from Jupiter's rotation axis, and the center of the field is off the center of the planet, so the magnetosphere performs complicated wobbles as the planet rotates. At times, when the solar wind allows it to, the magnetosphere can be 21 million kilometers in diameter. On the side away from the sun, its waggy tail extends beyond the orbit of Saturn. On the sunward side, it is a kind of punching bag for the solar wind, which kneads it in and out. It's a leaky bag, too. During its back and forth exercise with the solar wind, it emits bursts of electrons. John A. Simpson of the University of Chicago, says these electrons can be traced as far in as the orbit of Mercury. So through its magnetism, Jupiter's influence can be felt throughout the inner solar system.

The magnetosphere contains radiation belts 5,000 to 10,000 times as intense as the earth's Van Allen belts. They would be 100 times even more intense and an extremely dangerous place for traveling spaceprobes like Pioneers 10 and 11, if it were not for Jupiter's four largest satellites, Io, Callisto, Europa and Ganymede, which, together with little Amalthea, occupy orbits within the magnetosphere. The large satellites sweep up most of the high-energy particles in the radiation belts.

Nevertheless, the total energy of the Jovian radiation belts is many millions of times that of the earth's belts. Resupply of particles to the belts comes mainly from the planet's ionosphere, not from the solar wind. They bounce back and forth from pole to pole in the magnetic mirror set up by the planet's field lines, but they also participate in an in-and-out motion toward and away from the planet that appears so far unique to Jupiter's magnetosphere, having no parallel in the earth's. It is the inward stroke of this motion, which takes place in the equatorial plane of the magnetosphere, that endows the particles with their great energies.

As James A. Van Allen himself describes it, charged particles pulled out of the planet's polar regions get trapped along the equatorial plane of the magnetic field forming a plasma sheet that diffuses outward. This plasma sheet constitutes an electric current, and this current generates a weak magnetic field of about 5×10^{-5} gauss that rings the planet, combining with the planet's internally generated field.

Now, particles from the radiation belts that happen to be riding field lines that take them to the outer reaches of the magnetosphere can encounter this plasma sheet and its magnetic field and be deflected. This comes about because the buffeting of the solar wind twists the magnetic field lines and contorts the field near the outer edge of the magnetosphere, and the particles can jump off their lines.

Pressure drives the particles inward along the equatorial plane of the magnetosphere, because the sweeping action of the large satellites produces a dearth of particles in the inner part of the magnetosphere. As they fall inward, the particles are accelerated by the field generated by the plasma sheet. Near the planet, the field lines of the internal field bunch together and the accelerated particles can hop onto them for another trip to the outer magnetosphere. Continual recirculation builds up their energy.

Although the discovery of the earth's radiation belts was a surprise, Van Allen reminds us, those of Jupiter were expected. As long as 20 years ago radioastronomical studies had established that they had to exist. By 1956, two kinds of radio emission from Jupiter had been recorded, a steady flux at decimetric wavelengths and sporadic bursts at dekametric wavelengths. The decimetric flux could easily be attributed to the inner magnetosphere. The dekametric bursts could be attributed to plasma instabilities, and they seemed to be correlated somehow with the position of the satellite Io. It remained for Pioneer 11 to provide a plausible explanation of how Io does it.

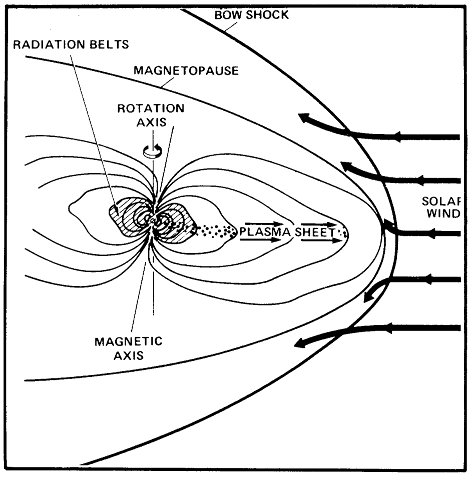
"The Io postulate may actually have been verified," says James Warwick of the University of Colorado. "The dekametric line of force goes through Io," says Walker Filius of the University of California at San Diego. "The spacecraft came close to the actual line of force. We don't know how close; we have to refine the location of Io and of the line of force." But, the spacecraft "saw an enormous spike of energetic electrons." The amount of energy in the spike is 3×10^{13} joules. The power of the dekametric radiation is 10^8 watts. "The number seems ample" to relate the two, Filius says.

The picture that comes out of all this is that Io serves as a kind of moving switch, a sliding electrical circuit closure. Io has an ionosphere, generated by sputtering of ions and electrons off its surface by collision with the magnetospheric particles. "Pioneer 10 detected the Io ionosphere," Warwick says. Io's orbital motion through Jupiter's magnetic field causes a segregation of positive charges on one side of the satellite and negative charges on the other. The electric potential thus generated between the two sides of the satellite is 400 kilovolts. When Io reaches the right position, a current is generated. It flows along the magnetic field lines from Io down to the conducting region of Jupiter's ionosphere and then back out to Io again. This is the spike of energetic electrons that Pioneer 11 found, and it generates the dekametric radio bursts.

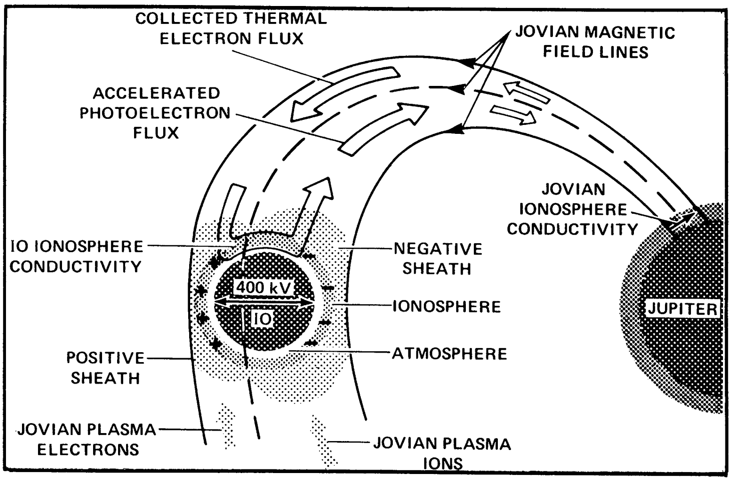
The magnetic field on which all of the foregoing phenomena depend is generated by a rather strange substance deep in Jupiter's interior, metallic hydrogen. Conditions there are so unsual that hydrogen becomes an electrically conducting liquid, and the planet's rotation causes a current flow that generates the magnetic field.

In fact, liquidity seems to be the most salient overall characteristic of Jupiter. Pioneer 10 found the planet to be in hydrostatic equilibrium, very symmetrical and with no gravitational irregularities. It is 70,000 kilometers from the cloud tops to the center of the planet, and some rather strange fluids occupy the cross section. The outer layer is gaseous hydrogen mostly. As the pressure increases the hydrogen gradually passes to a liquid state. The transition zone is around 1,000 kilometers down, and the temperature there is about 2,000°C. The liquid molecular hydrogen changes to liquid metallic (atomic) hydrogen at 25,000 kilometers down. The temperature here is 11,000°C and the pressure 3 million earth atmospheres. At the center the temperature is 30,000°C and the pressure 100 million earth atmospheres. The center is apparently inhabited by a small rocky core with 10 to 20 times the mass of the earth.

The radical differences in composition and physical state between Jupiter and the terrestrial planets lead astrophysicists to compare Jupiter to a star. Some months ago James Pollack of NASA's Ames Research Center showed that the evolution of Jupiter (and Saturn, too) could be neatly explained by postulating an evolutionary track like that of a star, but from which



Jupiter's magnetosphere (l) extends far beyond the visible planet. Orbiting inside the magnetosphere, Io (r) serves as a sliding switch, closing a circuit that generates Jupiter's dekametric radio waves.



Illustrations: NASA

the middle, thermonuclear-energy-producing stage was removed (SN: 1/17/76, p. 42). Now Pollack wants us to know that certain stages of that evolution took place at what, astronomically speaking, are breathtaking speeds.

With the rest of the solar system, Jupiter began about 4.5 billion years ago as part of a flat rotating gas cloud. In a few million years the planet began to take shape as a rotating cloud about a billion kilometers in diameter. It took a million more years to collapse to about 640 million kilometers. At this point, molecules in the cloud's center formed a lump that was in hydrostatic equilibrium, and after that things went fast. In three months, the cloud shrank to 640,000 kilometers, four or five times the size of today's Jupiter. The swift collapse raised its temperature to 50,000°C, and it remained thus, red hot for 100,000 years, during which its satellites formed. After that, Jupiter began to radiate energy like a white dwarf star, and began a very slow contraction that brought it to its present state.

On this strange world, this great liquid drop in the sky, this failed star with its violent history, can living creatures exist? The question at first seems absurd. But then one recalls that traces of the organic chemicals on which life is based exist in the Jupiter atmosphere. So maybe. . . . It could not be the creeping things, the beasts of the field, nor the fish of the sea familiar to our terrestrial scene. If we think of the fowls of the air, we may be getting a little warm, because Jovian life would have to float in the atmosphere, and it would have to be able to remain at a level where the temperature was hospitable for life processes. One speculative suggestion is floating gas bags, something like methane-filled jellyfish. But leaving in the realm of fantasy creatures that resemble living municipal gas tanks, we would find even tiny microorganisms to be surprise enough.

The Pioneer missions say nothing one way or another, but they have sparked a debate on the subject among specialists in exobiology. Cyril M. Ponnamperuma of the University of Maryland describes himself as optimistic. He points out that life depends first on chemical evolution, the production of organic chemicals out of the basic elements, hydrogen, carbon, nitrogen and oxygen, and then on biochemical evolution, the beginnings of self-replication and structuring of organisms. Fifteen years of laboratory work have shown that chemical evolution (up to amino acids even) is likely to take place where the required energy conditions are met.

Biochemical evolution is a problem not yet solved in the laboratory, but nature solved it on earth. The colors seen on Jupiter seem to indicate that the organic compounds are indeed there. Could the problem of biochemical evolution have been solved there also? It seems to be generally agreed that the presence of oceans was necessary to biochemical evolution on earth, and there are no oceans on Jupiter. So maybe not. But Ponnamperuma points out, there are droplets of water in Jupiter's atmosphere, and these might provide a microenvironment for life. "I'm reluctant to exclude biochemical evolution," he concludes. "Life is very hardy."

Just how hardy is the question, says Sherwood Chang of Ames. Although the organic compounds may be there, the environment is still a difficult one. "It's a question of ammonia toxicity," he says. Could an organism with a biochemistry such as we are familiar with survive in surroundings loaded with ammonia? It would require something that at least is not poisoned by ammonia and possibly something that positively thrives on it.

We may someday know the answer. One of NASA's future projects is a Juipter orbiter and a probe that will try to descend into the planet's weird atmosphere. Those efforts could get definite data on the presence or absence of life processes. ☐

By Jove! They do it in the air.

In the accompanying article Cyril M. Ponnamperuma lays out what seems to be the usual suggestion of exobiologists who are optimistic about life on Jupiter (and in similar environments), namely that microorganisms may have grown in a microenvironment provided by droplets of water in the Jovian atmosphere. At the recent COSPAR meeting in Philadelphia, experimental work was reported that appears to widen the possibilities of Jovian life. Robert L. Dimmick of the University of California at Berkeley, chairman of the aerosol sciences group at the Naval Biosciences Laboratory in Oakland, reported that microorganisms appear capable of living in a gaseous suspension without liquid.

It had been believed that suspended microorganisms would die, that for propagation, they needed a solid surface or a liquid. But working with the bacterium *Serratia marcescens*, Dimmick and his group found that microbes in aerial suspension not only had a mechanism for metabolizing sugar and so maintaining life, they even produced new DNA and showed evidence of dividing, that is, reproducing. The team found a doubling of the original number of the organisms and some indication of even a third generation.

Dimmick believes the results bear directly on the possibilities of life on Jupiter—he did the experiment at the request of NASA's Planetary Quarantine Group, which is concerned with means of avoiding biological contamination of other planets by our spacecraft—even though he didn't simulate the Jovian atmosphere. (Jovian gases are too explosive in the oxygenated terrestrial atmosphere to be comfortable to work with.) The experiments were done in an oxygen atmosphere, and *S. marcescens* is an oxygen-breathing organism. There is no free oxygen in Jupiter's atmosphere, so Jovian organisms would have to breathe other gases, but that is a biochemical possibility.