THE SOLAR SYSTEM ENVIRONMENT

Present knowledge of the planetary and interplanetary environments is quantitatively incomplete, and the concepts and ideas develop or change so rapidly that a description of this environment cannot be presented simply as a collection of equations, tables, and graphs. (This also includes the environment of the Earth, since there is still no reliable data on the Earth's magnetic and electric fields and on the Earth's atmospheric density and the associated phenomena.) Therefore, the description presented in this article is based on the latest available experimental data, or otherwise typical, quantitative information, which can be used for the preliminary estimates of a given mission requirement.

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Approximately 99.2% of the solar system's mass is accounted for by the Sun; thus, the Sun dominates the motion of all other objects and occupies a central position in the system. In addition to the Sun, the main components are the interplanetary space (including gas particles and associated magnetic fields and radiation), the asteroids, the meteoroids and comets, and the planets and their satellites.

The sun is a typical yellow dwarf star of spectral class G2 and is the energy source for essentially all the dynamic processes occurring in the solar system. The diameter of the sharp solar boundary is about 1.4×10^6 km, observed at the Earth-Sun distance of 1 astronomical unit, and subtends an angle of only ½°. The ultra-high temperatures and pressures of the sun's interior are estimated to be about 1×10^7 °K and 5×10^7 atmospheres; these values decrease rapidly as a function of the distance from the sun's center.

SOLAR MAGNETIC FIELD

The sun has a dipole magnetic field of the order of a few gauss. At the poles, the field is small, having opposite polarity in the northern and southern hemispheres. Near the surface of the sun, at sunspots, the local magnetic intensity is about 3,000 gauss; therefore, it is large enough to control the motion of the solar plasma. The solar magnetic field also decreases as a function of the distance from the sun. The total flux of electromagnetic radiation is approximately constant over a year's time, even during violent disturbances on the sun's surface. The bulk of the energy in the solar spectrum lies between 0.3 and 0.4μm, with approximately 1% of the energy lying beyond these limits.

SOLAR FLARES

Solar flares constitute a serious hazard to interplanetary flight, and to a lesser degree to the unmanned space vehicles in polar Earth orbits. Solar flares are explosive outbursts of electromagnetic radiation (including radio, ultraviolet, and x-ray wavelengths) and ionized matter (primarily protons and electrons) from the vicinity of a sunspot group. The Earth's magnetosphere prevents the solar flares from reaching the Earth below 70° latitude; at higher latitudes, solar flares reach Earth in approximately 8 minutes. The ultraviolet and x-ray radiation greatly increase the ionization in the *D*-layer of the Earth's ionosphere.

During the 11-year solar cycle, there are usually several flares per year, with durations of a few minutes to several days. The current solar cycle (20) began in October 1964, and the expected solar maximum for this cycle will begin in June-July 1968.

Flux and energy spectrum

The majority of solar flares which produce bursts of particles reaching the Earth do not attain relativistic energies (proton energies greater than about 2 BeV). The more frequent non-relativistic proton events have energy levels in the range of 30 to 100 MeV with flux levels of approximately 10^9 protons/cm^2 per flare; there are also electron events with energy levels greater than 40 KeV and flux levels from 10^7 to 10^9 electrons/cm^2 per flare.

Prediction of Flares

The accuracy to which it is possible to predict the occurrence of the most intense solar flares is currently being investigated, and quantitative equations for predicting the occurrence of a flare are developed. Estimates of conditions to be expected over six-month periods can be made, and favorable launching dates can be determined for a short duration mission (less than a week). There are two major theories concerning the solar flares: 1) The energy radiated by a large flare is caused by a sudden release of the stored magnetic energy in the chromosphere, when this energy exceeds some critical value. 2) Alternatively, the solar flares are caused by creation of a magnetically neutral point in the solar magnetic field, resulting in a pinch effect. However, neither of these hypotheses satisfactorily explains the origin of solar flares. Since flares occur near sunspots, their fields may be extensions of the strong sunspot fields; the occurrence and intensity of flares are related to the sunspot numbers.

INTERPLANETARY SPACE

Interplanetary space can be considered an extension of the sun's corona, with particles and magnetic fields from outside the solar system superimposed. The particle energies range from a few electron volts to relativistic energy levels.

Interplanetary Plasma

The streams of ionized plasma with frozen-in magnetic field move outward from the sun and extend in a continuously diminishing magnetic field; this effect is called the solar wind. (Other particles, solar flares, and cosmic rays accelerate along magnetic lines of force through space.) The velocity of the solar wind, as measured at about 37.5 Earth radii during the IPM-1 observations, is 340 km/s with particle densities of approximately 8 particles/cm^3. Mariner 4 measurements confirmed these values. During solar disturbances, the velocity of the solar wind may be as high as 1,000 km/s. The plasma temperature is about 2×10^5 °F. Hydrogen particles also occupy interplanetary space with a density of about 500 particles/cm^3. These particles are luminous (they absorb ultraviolet radiation and re-emit it as alpha quanta).

Magnetic Field

The typical intensity of the interplanetary magnetic field during solar quiet times is typically 2 to 5 gammas and has fluctuations of 10 to 20 gammas at the corresponding changes in solar-wind velocity. These fluctuations occur every 27 days.

Final manuscript received January 11, 1967.

Interplanetary Radiation

Both electromagnetic and corpuscular radiation permeate interplanetary space; this radiation varies with location and time. The electromagnetic radiations span the entire spectrum from radio-waves to high-energy gamma rays. The principal sources of corpuscular radiation are from galactic cosmic rays, trapped electrons and protons, and solar-flare protons and electrons. Naturally, there has been considerable recent interest in Earth's radiation environment, and there is considerable information available on this subject.[1]

Asteroids

Approximately 2,000 large asteroids have been discovered to date. Orbits of all sizes, eccentricities, and inclinations can be found among the asteroids, but most lie between 2.1 and 3.5 astronomical units (between Mars and Jupiter) near the plane of the ecliptic; all travel in direct motion about the sun. The inclinations and eccentricities are 9.5° and 0.15, respectively, with periods ranging from 3.5 to 6 years. Unlike the planets whose surfaces have been altered by a variety of different weathering forces, the asteroid surface may be reasonably free from such effects.

Asteroid distribution is not uniform. At distances from the sun (some fraction of the Jupiter's semi-major axis), there are noticeable drops in asteroid density. These gaps (Kirkwood gaps) are produced by Jupiter's repetitive attraction in an outward direction on bodies in this region. Twelve asteroids are found in Lagrangian libration points formed by the Jupiter in conjunction with sun; seven of these asteroids are to the east of Jupiter and five are to the west, each with a period equal to the Jovian year.

Ceres, Pallas, Juno, and Vesta, with a combined mass of one four-thousandth of that of the Earth, account for 75 to 80% of the total mass of all asteroids. Ceres, the largest asteroid is only 770 km in diameter, has a surface gravity of only 0.1 g, and probably does not hold a significant atmosphere. Of the 34 known asteroids which cross the Martian orbit, two-thirds have diameters in excess of 10 km. The diameters of small asteroids are measured by measuring their brightness. The albedos of the asteroids are highly variable; Vesta is especially bright, reflecting 55% of the sun's light. This leads to the speculation that it has a snow covering. Traces of the heavier gases may be the cause of the high albedos on some of the larger asteroids. A few show large fluctuations in brightness which are due to rotation of their nonspherical shapes. The total number of asteroids down to 20th magnitude may well exceed 100,000.

Meteoroid Environment

Interplanetary space contains many small particles (meteoroids) travelling in elliptical orbits around the sun. Meteoric matter may be classified as asteroidal or cometary. About 90% of the total meteoric debris accreted by the Earth is associated with present or past comets. Meteoric matter may be expelled from comets by diffusion effects and also generated by dust expulsion from the lunar surface caused by meteoroid impacts. The Earth's gravitational force may be extensive enough to perturb and accrete this meteoric matter. The Earth may also be primarily responsible for the organization of meteoric matter into heliocentric streams at a solar distance of 1 astonomical unit. The meteoric concentration in this belt, having particles heliocentrically orbiting in a toroidal-like region, may be several times

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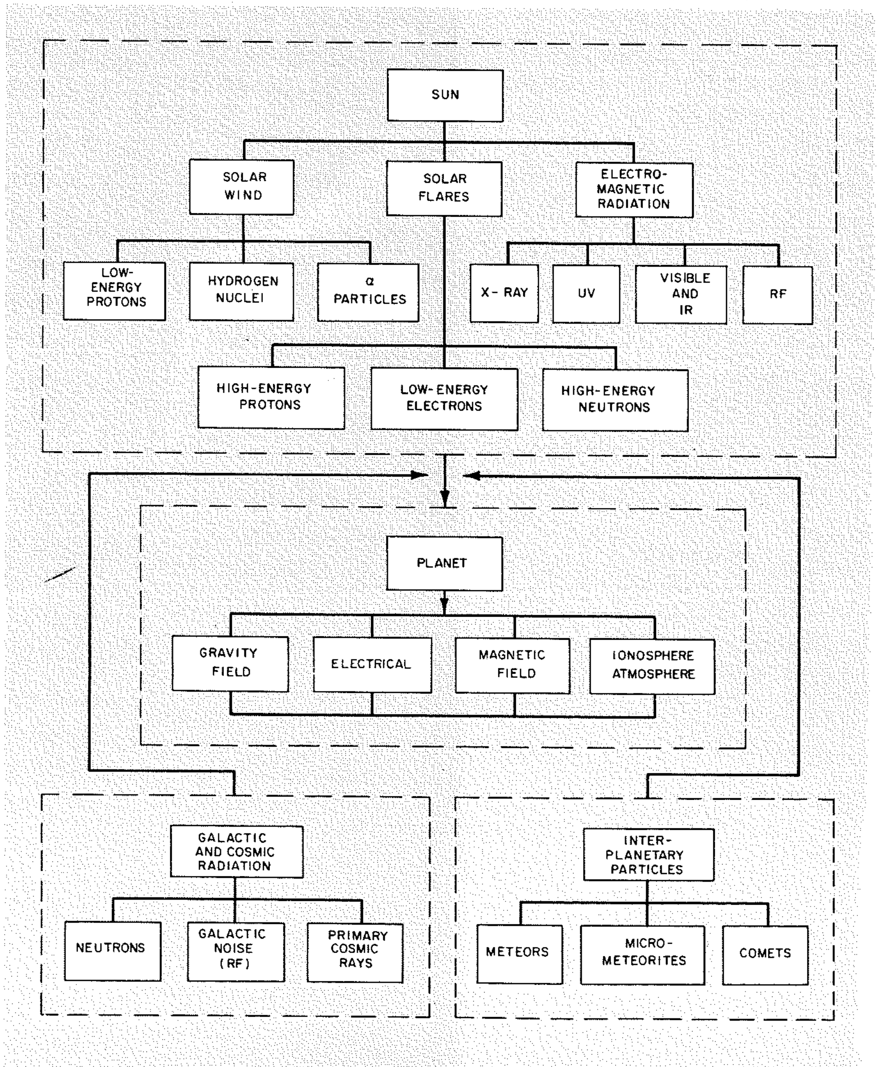
Fig. 1—Interaction of the sun and the interplanetary environment with the planetary environments.



greater than the concentration found in interplanetary space. Thus, meteoric matter from interplanetary space, as well as the most immediate environs, intercept the Earth, suggesting an envelope of meteoric matter peculiar to the Earth.

Particles orbiting the planet are assumed to be predominantly in elliptical orbits, which suggests a nearly isotropic particle flow direction. The mean particle velocities near the planet are probably equal to the escape velocities of the particles at a low altitude from the planet's surface and are assumed to vary inversely with the square root of the planetocentric distance.

The observed meteoroid flux in the near-Earth region is not constant, but has random variations of orders of magnitude. This is believed to be due to meteoric showers which may be evident for as long as a few days. Seasonal and diurnal flux variations are also quite significant.

At near-solar distances, particle density is most likely to decrease because of the effects of solar energy. Therefore, Mercury, for example, may accrete particles having an average density less than that found near the Earth; whereas at Mars, Jupiter, and possibly even Pluto, the density of captured meteoric matter, primarily of cometary origin, may be slightly higher than that found near the Earth.

Micrometeoroids do not present the principal particle hazard to a space vehicle since the flux of larger particles is very low; therefore, the danger of collision with the space vehicle structural materials is negligible. Extremely small particles with masses less than 10^{-6} gm will not have enough energy to do great damage even when they impact at very high speeds. Particles with masses in the range of 10^{-6} to 10^{-3} gm are the most dangerous since their fluxes are high enough to give finite collision probabilities. To assess the potential damage to a space vehicle, it is necessary to know the frequency of collisions expected, the characteristics of the particles encountered (mass, size, and velocity) and the characteristics of hypervelocity impact (such as, penetration depth, and crater size).

As a result of the recent MARINER 4 cosmic-dust experiment, the following conclusions have been drawn:

1) The interplanetary dust-particle flux increases as the heliocentric distance from the sun increases.
2) The cumulative flux-mass distribution curves vary as a function of $m^{-0.55}$ (where m is the particle mass) near the planets, and as a function of $m^{-0.9}$ in interplanetary space.
3) There is no statistical evidence of well-defined dust-particle streams.
4) There is no measurable enhancement of the flux in the vicinity of Mars (i.e., no influence from the asteroidal region).

Comets

Comets, although seldom seen, are a part of the solar system. Originally, all comets had long periods (i.e., their eccentricities were greater than 0.99 and less than 1). Moving in these extended ellipses with periods ranging from 10^3 to 10^6 years, they would often be perturbed sufficiently either to completely remove them from the solar system (i.e., eccentricity greater than 1) or to lower their eccentricity to a period comparable to that of the planets. A considerable number of short-period comets have accumulated within the orbit of Pluto. Short-period comets captured by a planet have orbits with an aphelion distance about equal to the semi-major axis of the captor. The short-period comets are grouped into families associated with each of the larger planets.

A comet is composed of three parts: the nucleus, the coma, and the tail. The nucleus has a diameter of about 1 km, it is very dense with masses of 6×10^{12} to 6×10^{16} tons. Surrounding the nucleus is a gaseous hull known as the coma. The mass of gas liberated by the nucleus usually consists of OH, NH, CH, CN, or C_2. The tail contains molecules of N_2, CO, and CO_2 and may attain lengths of several hundred miles.

There are two assumptions on the nature of the comet's nucleus:

1) The nucleus is an icy conglomerate of compounds of nitrogen, oxygen, carbon, and hydrogen with imbedded silicates and metals (proposed by Whipple). Therefore, as the comet approaches the sun, the ice evaporates resulting in gases forming the coma and tail. This model is more generally accepted. The evaporated particles at first travel in the same orbit as the nucleus of the comet, later as a function of time, solar wind, and perturbations by the planets, this cloud spreads into a large swarm of meteoroids. These meteoroids eventually spiral into the sun. During this process, each meteoroid is dispersed from its cloud to such an extent that it can no longer be associated with the cloud; this leads to the birth of sporadic meteoroids of cometary origin, with a unique orbital path for each particle. The probability of a space vehicle hitting the nucleus of a comet is extremely small; however, traveling through the coma for any period could critically alter a vehicle's velocity.

2) Recently, a theory has been proposed which accounts for the observed excess light emissions, explosive outbursts, and contraction and extension of the coma. This theory states that the coma is some form of a magnetized plasma.

A study has been conducted by the Philco Corporation demonstrating the feasibility using a modified MARINER-4 spacecraft to obtain selected scientific data from comets in 1969 and 1970. Scientific instrumentation has been selected: 1) to measure the distribution of matter and magnetic flux through the coma; 2) to observe the nucleus of a comet; 3) to determine the chemical composition of cometary material; and 4) to measure the physical and chemical properties of close-approach asteroids.

PLANETS AND THEIR SATELLITES

According to their physical characteristics, the nine planets are classified either *Terrestrial* (resembling Earth) or *Jovian* (resembling Jupiter). Mercury, Venus,

TABLE I—Physical Characteristics of the Planets (Approximate Values)

Planet	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
No. of Natural Satellites	0	0	1	2	12	9	5	2	
Equatorial Radius:									
(in Earth diameters)	0.379	0.956	1.00	0.535	11.14	9.47	3.69	3.50	1.1
(in 10^3 km)	2.42	6.10	6.378	3.41	7.14	6.04	2.35	2.23	7.
Mass Including Satellites (Earth = 1)	0.0546	0.81498	1.01230	0.1077	317.89	95.12	14.52	17.	0.8 ± 0.1
Equatorial Surface Gravity (Earth = 1)	0.380	0.893	1.00	0.377	2.54	1.06	1.07	1.4	0.7
Semimajor Axis, AU	0.387	0.723	1.00	1.52	5.20	9.53	19.18	30.06	39.52
Perihelion Distance, AU	0.308	0.718	0.983	1.381	4.951	9.008	18.277	29.80	29.69
Aphelion Distance, AU	0.467	0.728	1.017	1.666	5.455	10.07	20.09	30.32	49.34
Orbital Eccentricity ($e \times 10^{-3}$)	206.	6.79	16.73	93.3	48.5	51.6	44.31	7.34	248.11
Mean Orbital Velocity (Earth = 1)	1.607	1.176	1.00	0.807	0.438	0.324	0.228	0.182	159.1
(in km/sec)	47.90	35.05	29.77	24.02	13.05	9.64	6.797	5.43	4.73
(in 10^3 ft/sec)	157.19	114.96	97.70	78.81	42.82	31.60	22.30	17.80	15.6
Period of Revolution (Earth = 1)	0.241	0.617	1.00	1.88	11.86	29.46	84.0	164.8	247.7
Orbital Inclination to Ecliptic, deg	7.00	3.39	0	1.85	1.31	2.49	0.77	1.77	17.16
Inclination of Equatorial Plane to Orbit, deg			23.4	25.2	3.12	26.7	98.0	29	
Axial Rotational Period	88d	150d to 280d	23h 56.07d	24h 37.38m	9h 53m	10h 26m	10h 42m	15h 48m	
Escape Velocity (10^3 ft/s)	13.6	33.5	36.7	16.5	197.5	119.5	72.5	82.4	31.3

Mars and Pluto are Terrestrial planets; Saturn, Uranus and Neptune are Jovian (or giant) planets. Table I lists the major physical characteristics of the planets. Fig. 1 summarizes the possible interactions of the sun and the interplanetary environment with environments of the planets. The remaining sections of this paper discuss each planet and its environment.

MERCURY

Mercury has received increased attention during the last two years, since its dark side may contain the greatest abundance of light elements in the solar system (elements of importance both for life support and as propellant chemicals); thus, the planet is of interest as a logistic supply base, in addition to its basic scientific significance.

Planetary Rotation

Mercury is the smallest of the nine planets, with a diameter of about 5,000 km. As a result of being close to the Sun, Mercury is constrained to rotate and revolve in the same period of 88 days, just as the Moon keeps the same face to the Earth. Nevertheless, only 30% of the planet is in continual total darkness, since the ellipticity of its orbit ($e \leqq 0.2$) causes rather large librations. Recent radar observations show that the rotation of the planet Mercury is direct with a sidereal period of 58.4 ± 0.4 days. For an eccentricity of 0.2, the variation between perihelion and aphelion is a factor of 3.4. This agrees with the effect of the solar quadrupole moment on the excess advance in planetary perihelion. Thus, it is possible for Mercury to rotate with a period exactly two thirds of the period of revolution (a resonance lock at an average period of 58.65 days).

Atmosphere

From polarization studies, it is assumed that Mercury probably has a weak atmosphere with a possible atmospheric thickness of about 25 meters and surface pressure of 1 mb. Assuming that the gases of this atmosphere were produced after the planet cooled to its present temperature, the most likely constituents are carbon dioxide, oxygen, sulfur dioxide, and argon.

Temperature

Mercury exhibits the greatest temperature extremes of any planet in the solar system. At the subsolar point, the temperature varies from 688°K at perihelion to 558°K at aphelion (as calculated from its black body curve and the solar constant). On the dark side, the temperature approaches absolute zero (about 25 to 28°K). Because of the large librations, there is a fairly wide belt near the terminator with Earth-like temperature, only in this region are surface landings feasible. For the illuminated side, there appears a significant difference in microwave and infrared temperature measurements. For planet-ocentric angles between the Sun and Earth of 0 to 120°, the disk temperature reduced to the mean solar distance of Mercury is 1,100 to 250°K for microwave observations and 600 to 40°K for infrared. If this apparent difference is real, then there are probably some unexpectedly high temperatures (in the range of 200 to 300°K) in the unilluminated hemisphere possibly due to radioactive heating.

Interior

There is theoretical evidence that the Mercurian interior is in a molten metallic state, with a concentration of radioactive elements. Therefore, it possibly has a magnetic field similar to Earth along with trapped radiation (radiation belts).

Surface

Mercury's surface is assumed to be similar to that of the Moon, since the albedos and polarization curves of both bodies are similar. The increase in the brightness of Mercury from quarter to full phase, produced by disappearance of shadows, also indicates that the topography of Mercury is similar to that of the Moon. In the temperature belt near the terminator, libration will produce a "day and night" causing the surface to be alternately heated and cooled. The surface in this area is probably cracked in many places. The meteoric erosion of the dark side of Mercury is probably insignificant; however, the constant meteoric bombardment may disturb any anticipated stratification of surface material.

VENUS

The lack of information on the chemical and physical properties of the atmosphere precludes any accurate deductions of the nature of the surface. Likewise, information concerning any permanent markings, including the planet's oblateness is obscured. However, radio emission experiments, conducted by the Owens Valley Observatory in 1964, revealed that this emission is generated by the surface of the planet (not by the atmosphere). The dielectric constant of 2.5 indicates that Venus has no large bodies of water and that the surface characteristics correspond to dry, unconsolidated rock such as sand or asphalt.

All estimates of the diameter of Venus are not of the solid planet, but of the planet plus atmosphere. Consequently, the period of rotation and the inclination of the axis are very difficult to determine. Several estimates of the period of rotation have been made based on visual and photographic observations of the cloud markings. However, these are not very accurate, since one could not use the same model for the lower atmosphere on the day and night sides.

In addition to these uncertainties, the extremely high surface temperatures on the night side as measured by MARINER 2 must be explained. These high temperatures must be accompanied by high surface pressure and both must be measured. Venus landers will be extremely difficult to design. With the high surface temperature, probably high surface pressure, clouds which may be dust, and no knowledge of surface characteristics, an early entry capsule must allow for as many extremes as possible.

Atmosphere

Recent evaluations of the Venusian atmosphere indicate that molecular nitrogen forms the major portion of the atmosphere (with about 5% CO_2). In absence of positive spectroscopic identification, the major constituent creating the high total pressure must therefore be a gas whose emission lines are absorbed in the Earth's atmosphere (possibly nitrogen gas). The infrared radiometer on MARINER 2 was designed to measure the infrared radiation from Venus in two wavelength regions: one centered at the 10.4μm carbon-dioxide band, and the other centered at the 8.4μm water-vapor band; neither was detected. However, in a February, 1964, experiment by Johns Hopkins University an automatic telescope spectrometer unit, carried by balloon to an altitude of 27 km above the Earth, measured water-vapor absorption in the 1.3μm wavelength band. Assuming that the water vapor above the visible clouds is distributed gravitationally with a uniform mixing ratio, the water vapor content was computed for the assumed pressures of 90 mb and 600 mb. The results are 12.3×10^{-3} g/cm^2 for a base pressure of 90 mb, and 2.9×10^{-3} g/cm for 600 mb. A choice between these values, or in this range, must await more knowledge about the actual pressures.

Clouds

From MARINER 2 data, it is estimated that the cloud layer is 15 to 20 miles thick, with a ceiling of about 45 miles. MARINER 2 found no evidence of breaks in the clouds as were previously assumed to exist; temperatures in the cloud layer were found to be the same on the dark side as on the light side.

The data does not show any clear-cut evidence of asymmetry in the limb-darkening, except for an anomaly on the southern part of the terminator scan. In particular, the light and dark side temperatures were qualitatively the same. The anomaly was about 10°K cooler than expected on the basis of symmetrical limb-darkening. One obvious interpretation of this temperature anomaly is that the clouds were locally higher or more opaque, or both.

Magnetic Field

Magnetometer data obtained as Mariner 2 passed Venus gave no evidence of Venusian magnetic field at any point on the trajectory. No rise in the average value of the magnetic field above the value of the interplanetary field was detected, which could be attributed to the planet. The sensitivity of the magnetometer was such that a field strength change of about 4γ on any axis would have been detected. ($1\gamma = 10^{-5}$ gauss, the magnitude of the Earth's field at the equator is about $30{,}000\gamma$.) During encounter, a slow change of about 10γ was observed. However, this change was attributed to a temporal change in the interplanetary magnetic field. No fluctuations with periods from 1 second to 1 minute and amplitudes of the order of 3γ were observed. (These fluctuations are characteristic of the transition region just outside the geomagnetic field.) Simultaneous measurements by the Mariner 2 radiation detectors failed to reveal any effect associated with a planetary field such as trapped radiation or a modulation in the flow of solar plasma.

The above results do not necessarily mean that Venus has no magnetic field, since the solar wind could confine a weak field to a limited region close to the planet. The observations indicate that the field does not extend out to the Mariner 2 trajectory (the distance of closest approach from the center of Venus was approximately 41,000 km). Theoretical models of the interaction of the solar wind with dipole magnetic field indicate that the dipole moment of Venus, if it exists, is approximately perpendicular to the Sun-Venus line, and it is less than 0.1 that of the Earth. If Venus has a more complicated magnetic structure than the Earth, so that higher-order multipoles are important, the surface field could be larger than the Earth's field without increasing the strength of the field along the Mariner 2 trajectory to an observable value. The cosmic-ray flux at the top of the Venus atmosphere may correspond to the cosmic-ray level in the Earth's polar regions.

Solar Plasma

The following conclusions have been drawn from the plasma data obtained near Venus: 1) The plasma flux was not observed to vanish as would be expected if the probe had entered the magnetosphere of Venus. 2) There was no clear evidence of passage through a bow shock wave associated with Venus. 3) There was a gradual increase and subsequent decrease of the plasma velocity as the spacecraft approached and later receded from Venus. 4) The average momentum flux in the solar wind near Venus was 3.8×10^{8} dyne/cm^{2}. Since this is not an unusually high value, the Venus magnetic field was probably not compressed an unusually large amount at the time of encounter.

Mass of Venus

Pending final reduction of data, a preliminary calculation of the mass of Venus is 0.81485 that of Earth, with an error probability of 0.015%. Since the Earth's mass is known to be approximately 5.077×10^{24} kg, Venus' mass becomes approximately 4.870×10^{24} kg.

Future Missions

To determine the physical characteristics of Venus, the next generation of space vehicles is expected to pass within 3,000 nmi of the planet's surface. A Mariner-type spacecraft probably will encounter the planet on the dark-side, quickly pass over the terminator, and swing over the sunlit surface.

The atmospheric measurements will constitute the prime mission; in addition, an ultraviolet photometer to investigate the upper atmosphere will be included.

Trapped-radiation detector and magnetometer experiments will measure the magnetic field intensity and the associated radiation belts of Venus. A plasma probe will be included to investigate the interplanetary plasma and to measure the possible discontinuities in the plasma in the vicinity of the planet. Multispectral TV cameras, and infrared and microwave radiometers will determine the cloud characteristics, the anomalies in the albedo, the layers and the surface characteristics of the planet. A cosmic-ray telescope and cosmic dust detector must be included for the detailed investigations of the nature of the planet itself. However, if the Mariner-type spacecraft will be used, most of these experiments may be omitted due to power shortage and the stringent temperature control requirements.

Probably the most attractive trajectories in the multiplanet mission exploration will be: 1) use of close Venusian passages during solar probe missions; 2) Venus-swingby mission mode for manned exploration of Mars; and 3) a combined Venus-Mercury flyby mission mode.

MARS

The preliminary results of Mariner 4 answered some of the existing questions on the physical characteristics of Mars, such as the magnetic field intensity, intensity of the trapped radiation, cosmic-ray intensities, and some surface characteristics; also preliminary atmospheric models were derived from the occulation experiment. The exact composition of the Martian atmosphere, the cloud characteristics (especially "blue haze" and "yellow clouds"), and the geophysical characteristics of the surface, however, remain unsolved. Also, the magnetosphere boundary and ionosphere of Mars are uncertain. The near or complete absence of a static magnetic field on Mars may imply the direct interaction of the solar wind and cosmic-rays with the atmosphere and surface of Mars (interaction of the cosmic-rays with the surface material will produce radioactivity in the outer layers of the planet; if this is so, it is possible that Mars has a volcanic activity). Life on Mars, such as on Earth, is not possible due to atmospheric composition, but there could be some other type of life form.

The following is a summary of the results obtained by the Mars Mariner 4 experiments[2].

Surface Age and Craters

About 100 craters were photographed by Mariner 4, and the size of the craters vary from 10 to 100 km in diameter with configurations very similar to those of the Moon. The crater walls slope at angles up to about 10°, and there must be approximately 10^{4} craters. The Mars surface is very old—based on Mariner 4, about 2 to 5×10^{9} years; however, this estimate is challenged. According to some investigators, the age of the visible Martian surface is approximately 300 to 800×10^{6} years.[3,4,5]

In the first four pictures from Mariner 4, the very high solar illumination of the terrain significantly reduced the visibility of surface features. Pictures No. 5 through 14, however, present a view of a densely cratered surface of widely different degrees of preservation. A few elongated markings of diffuse nature are present as yet, but no conclusions are offered concerning them. On photograph 13, one such feature looks like the edge of a very large crater, and perhaps lies near the border of the Martian dark area. In the southern subpolar latitudes (where the season during the encounter was late midwinter), some craters appear to be rimmed with frost. Although the path of flight crossed several "canals" sketched on the existing maps of Mars, no trace of these features was discernible. However, the visibility of many Martian surface features, including the "canals", is variable with time. No Earth-like features such as mountain chains, great valleys, ocean basins, or continental plates were recognized. Clouds were not identified and the flight path did not cross either polar cap. However, recent models of the Martian atmosphere suggest that small crystals of frozen carbon dioxide are present at all times, even at high altitudes (about 100 km above the surface of the planet).

The principal topographic features of Mars in the areas photographed by MARINER 4 were interpreted as not having been produced by stress and deformation originating within the planet, in comparison to the case of Earth, which is internally dynamic. The lack of internal activity is also consistent with the low magnetic field on Mars and therefore in contradiction to the possibility of the volcanic activity.

Surface Spectroscopy

According to Dr. Murray, the light-to-dark variation of the Martian surface is due to the slope changes across the craters: some parts of the slope are directly illuminated by the sun, others have a very low sun angle across them. Therefore, pictures would show the light-to-dark variations across a crater, even if there is no shadow formed (experimenters have not yet identified any shadows on the MARINER 4 photographs). The characteristic whitening on MARINER 4 pictures No. 14 and No. 16 is identified by Dr. Murray as frost.[6]

From the March 19, 1965, ultraviolet observations (1965 Mars opposition), it may be concluded that the spectrum of Mars can be divided into several regions where different effects are important in producing the reflectivity of the entire planet. Below 3,000 angstroms, Rayleigh scattering predominates. In the 3,000 to 4,000 angstrom range, Rayleigh scattering should contribute about 0.01 to the total reflectivity, and large-particle scattering about 0.01 to 0.02. The reflectivity of the polar cap should be approximately constant at all wavelengths at about 0.15 to 0.25 (that is, slightly higher than the light areas in the red region of the spectrum). The contrast of surface features should be reduced essentially to zero in the 3,000 to 4,000 angstrom range. Maximum limb brightening should occur at 4,500 to 5,000 angstroms owing to Rayleigh scattering. Between 4,000 to 5,000 angstroms, the increasing reflectivity of the surface should begin to predominate in determining the total reflectivity. Quantitative testing of the MARINER 4 TV was done to simulate Martian light-and-dark-area albedos between 0.18 and 0.07 respectively.

Magnetometer Experiment

One half hour after the closest approach to Mars (13,201 km) magnetic measurements changed from 5 to 10 gamma, which possibly indicated the passage through the Martian shock wave. However, this is not certain. It is possible that Mars has a weak magnetic field, but no shock front, and that shock may be produced by the interaction of the solar wind with the Martian atmosphere. According to the magnetometer experiment, the magnetic moment ratio of Mars to that of Earth may be in the range of 10^{-3} to 10^{-4} with the shock front located at 10,000 km and 20,000 km, respectively. The corresponding upper limits of the equatorial magnetic field at the surface of Mars is 200 to 100 gamma.

Cosmic-Ray Experiment

The cosmic-ray telescope on MARINER 4 was designed to measure: 1) the energy spectrum and flux of protons, 2) the flux of the α-particles in the energy range of 1 to 170 MeV, and 3) the flux of the electrons in the energy range of 20 to 120 keV. No electron particles were detected. This implies that the very weak Martian magnetic field does not trap energetic particles and that Mars is directly exposed to bombardment by cosmic rays and solar plasma (solar wind). The interaction of the cosmic rays and solar plasma with the Martian atmosphere produces high-energy neutrons, which interact with the Martian surface to produce radioactive materials close to the surface of the planet.

Charged-Particle Measurements

During the Martian encounter all the detectors operated properly and provided a large volume of data on solar proton and electron events. And no particle effects whatever attributable to Mars were detected despite the close approach of the spacecraft. (The intensity of electrons $E_e > 40$ keV did not exceed 6 electrons/cm^2-s over any 45-second sampling period. A similar trajectory past the Earth would have encountered particle fluxes as high as 10^7 electrons/cm^2-s).

Cosmic-Dust Experiment

The cosmic-dust detector on the MARINER 4 has measured the flux and mass distribution of dust particles in interplanetary space between 1.0 and 1.4 astronomical units. As the spacecraft approached the Mars orbit at approximately 1.4 astronomical units, the value of the flux started to increase. The mean value of the flux between 1.4 and 1.5 astronomical units was about 2.7×10^{-4} particles/m^2-s (particle masses $\geq 5 \times 10^{-11}$ gram) which is still representative of an increase in the mean flux value as the distance from the Earth's orbit increases in the antisolar direction.

Mars Atmosphere

Re-evaluation of the occulation experiment data resulted in the best estimated range of the probable Martian Atmosphere shown in Table II.

JUPITER

Interplanetary mission planning for the next two decades includes fly-by missions to Jupiter. NASA anticipates sending a probe to 5 atmospheric units to examine the problem of passing the asteroid belt to reach Jupiter (about 5.2 atmospheric units). One of the first problems to be solved is how to design a space probe and instruments strong enough to withstand the enormous pressures near the planet's surface. Jupiter is one of two bodies in the solar system that man will not be able to exist on (the other being the Sun) as he cannot yet shield himself against the high surface gravity. Thus, primary exploration will be with unmanned probes, orbiters, and landers.

From Earth, Jupiter appears elliptical in shape, due to its thick atmosphere and rapid rotation. Its period of revolution is not fixed, but depends upon the particular part being observed. Although the equatorial region has a rotation period of 9 hours, 50 minutes, most of the rest of the planet rotates at 9 hours, 55 minutes.

Atmosphere

Calculations based on the polar flattening have shown that the outer layers of Jupiter are gases: mainly hydrogen, helium, and methane. The quantitative distribution of these gases presents a a highly controversial problem. Some investigators suggest that the Jupiter atmosphere contains large amounts of helium, small quantities of neon and argon, and very slight traces of other constituents.

Ionosphere

Calculations of the equilibrium electron density result in an ionospheric layer

TABLE II—Probable Mars Atmosphere

Property	Range
Surface pressure (mb)	5.0 to 10.0
Surface density (gm/cm³)	0.68 to 2.57×10^5
Surface temperature (°K)	275 to 200
Stratospheric temperature (°K)	100 to 200
Acceleration of gravity at surface (cm/sec²)	375
Composition:	
CO_2 (by mass)	28.2 to 70.0
CO_2 (by volume)	20.0 to 68.0
N_2 (by mass)	0.0 to 71.8
N_2 (by volume)	0.0 to 80.0
A (by mass)	0.0 to 30.0
A (by volume)	0.0 to 32.0
Molecular weight (mol^{-1})	31.2 to 44.0
Specific heat of mixture (cal/gm-C)	0.153 to 0.230
Specific heat ratio	1.37 to 1.43
Adiabatic lapse rate (°K/km)	—3.88 to —5.85
Tropopause altitude (km)	17.1 to 19.1
Inverse scale height stratosphere (km^{-1})	0.0705 to 0.199
Continuous surface wind speed (ft/sec)	155.5 to 220.0
Peak surface wind speed (ft/sec)	390.0 to 556.0
Design vertical wind gradient (ft/sec 1,000 ft)	2

with a maximum density of approximately 7×10^5 and 1×10^6 electrons/cm^3 at altitudes of 200 and 120 km, respectively, above the cloud level.

The results of the above electron density calculations may have an important bearing on the validity of those hypotheses which assume the ionosphere of Jupiter as a direct participant in the generation of the decameter radiation. For example, a mechanism has recently been proposed which requires electron densities of the order of 10^8 electrons/cm^3 in the Jovian ionosphere.

Albedo of Jupiter

As an exterior planet Jupiter shows only gibbous phases; however, because of the large size of the orbit compared to that of Earth, the maximum phase angle is only 12° at quadratures, and the phase effect shows up only as a slightly increased darkening of the edge at the terminator.

Recent observations of Jupiter in the ultraviolet spectrum showed that the albedo is minimum at 3,500 angstroms; a further increase in the wavelength leads to an increase in the albedo. The high value of the albedo indicates the presence of a dense, cloud-laden atmosphere. Photoelectric measurements of the monochromatic flux from Jupiter in the region from 3,400 to 10,000 angstroms indicates that the bolometric geometrical albedo is 0.28. The uncertainty in this value is estimated to be about 10%. The bolometric bond albedo of Jupiter is 0.45.

Temperature

The vertical temperature profile in the atmosphere above the clouds were theoretically computed for various atmospheric models. The following are some of the important results of the calculations:

1) Assuming the atmosphere to be in radiative equilibrium, the approximate temperature profile for a gray atmosphere indicates that the temperature near the cloud top decreases with altitude slowly to reach an asymptotic value of 128°K at approximately 35 km to 70 km. These temperature profiles are consistent with the recently measured temperature in the far-infrared and in the millimeter region of the planetary spectrum.
2) The temperature of the upper atmosphere of Jupiter has been calculated assuming that 50% of the ultraviolet energy deposited in the thermosphere is converted to heat and the energy is conducted downwards to the mesopause to be radiated away by CH_4 and NH_3. At mesopause levels of 187 km and 106 km, the corresponding temperatures are found to be 140°K and 135°K, respectively.
3) The equilibrium temperature for Jupiter, based on an albedo of 0.45, is 105°K ±3°K. The radiometric temperature has been measured by Dr. Murray to be 128 ±2.3°K (which is significantly larger than the equilibrium temperature of 105°K). However, since the radiometric temperature is actually a brightness temperature measured in the 8 to 14μ wavelength region of the spectrum, its interpretation is complicated by the effect of Jovian atmospheric absorption.

Jupiter's Interior Structure

Various theoretical models of the internal structure of Jupiter, calculated after 1930, had suggested the following constitution: a relatively small inner core of rock and iron, surrounded by a thick mantle of several varieties of water-ice and other ices under very high pressures and at very low temperatures, and above this an extensive liquid and gaseous atmosphere whose uppermost layers only are visible. However, the discovery in 1954 of the emission by Jupiter of strong pulses of nonthermal radio noise at wavelengths close to 15 meters led astronomers to question such models and to consider the possible presence of hot energy sources under a solid surface, at a moderate depth below the optically impenetrable cloud cover. The recurrence of radio emission in certain longitudes indicates the existence of sources of energy rotating with a constant period of 9 h, 55 m, 29.6 s. and suggests the presence of a solid surface under the clouds. Also, the difference between the radiometric temperature and the equilibrium temperature may possibly be explained by the Jupiter interior structure. The following are the various hypothetical explanations for the temperature differences:

1) The difference between the equilibrium and radiometric temperature represents radiation of heat from the interior of Jupiter.
2) Jupiter's atmosphere is heated by the interior, also continued cooling and gravitational contraction energy contribute to Jupiter's heat budget.
3) Pressure-induced temperature transitions in molecular hydrogen produce a greenhouse effect (only 30 km-atm of molecular hydrogen is sufficient to produce such a temperature).
4) Jupiter is merely reradiating absorbed sunlight as a gray body with a temperature of 145°K and an emissivity of 0.27. This temperature is comparable to the temperatures at the top of the Jupiter cloud layer. However, the expected atmospheric absorption by methane, ammonia, and possibly hydrogen is probably not constant with wavelength; therefore, this model oversimplifies reality.
5) Jupiter's interior has a solid metallic hydrogen core having a radius $R = 0.80R_p$ (where $R_p = 7 \times 10^4$ cm is the mean radius of the planet) and the temperature at the bottom of the molten mantle is about 2,000°K. It may be possible to transport heat from the interior to the surface without melting the mantle if the temperature for convective creep or radiative transport in the solid mantle does not exceed the melting temperatures.
6) Radioactivity, meteor bombardment, tidal friction (tidal force due to the Jovian satellite Io), and magnetic field decay were also investigated to determine if they could provide sufficient heat to explain the radiometric temperature.

From the above analyses, it can be concluded that if the radiometric temperature is due to the heat from the interior, the mantle is probably melted and convective. Then it is possible that Jupiter is still radiating the original contraction energy. Neither radioactivity, meteor bombardment, tidal friction, nor magnetic field decay present an alternative source of energy to explain the radiometric temperature. Therefore, it is obvious that present theoretical models of the internal structure of Jupiter are in need of considerable revision.

Red Spot

The problem of the origin of the *red spot*, an oval formation situated in the southern hemisphere of Jupiter, has not yet been solved. The red spot lies at a latitude of about −23° and differs from the other details of the visible surface of the planet not only by its regular shape, but also by its remarkable stability during the 150 years since its discovery. During this time, the latitude of the spot has remained almost constant, its longitude varies continuously. These variations are independent of the rotation of the visible Jovian surface. Spots on the visible surface of Jupiter are recorded in two systems: System I is based on a 9-hour, 50-minute rotation period, and System II is based on a rotation period of 30.003 seconds. System II is used for spots in the equatorial zone.

A number of hypotheses have been put forward to explain the physical nature of the red spot, and these can be subdivided into two groups: 1) The red spot is a solid or liquid body which floats like an island in the gaseous atmosphere condensed by high pressures; 2) the red spot consists of pure gas or a mixture of gas and aerosols.

The derivation of the details of the above hypotheses was, as a rule, based only on the dynamical features of the red spot (velocity of rotation) and purely qualitative characteristics of the color of the spot and conditions of visibility. No physical and optical investigations of the red spot were carried out.

The dynamics of the Jovian atmosphere has not yet been studied sufficiently, either theoretically or observationally, to be able to give an unambiguous explanation of the observed features of this unique formation on Jupiter.

Atmospheric Dynamics

The permanent markings observed on Jupiter are the bright cloud belts (about seven or eight). These belts are parallel to the Jupiter's equator and are separated by darker zones. These markings are irregular, subject to significant variations in latitude, and the boundaries between the belts and zones often take on a serrated shape.

Color variations across Jupiter's disk have not yet been explained. However, it is suggested that these variations may be due to traces of sodium, potassium, or some other metal, and certain free radicals at cloud level in the atmosphere. It is assumed that the dark zones, parallel to Jupiter's equator, mark the Jovian equivalent of the terrestrial trade winds, based on the existence of rapid equatorial currents in the fluid layers of rapidly rotating planets such as Jupiter and Saturn.

It is difficult to assume that the atmosphere remains fluid at a depth of 1,000 km below the visible surface, unless there is a rather rapid rise of the temperature as a function of depth. The most acceptable model of Jupiter thus can be assumed to exhibit a shallow, fluid atmosphere, a solid mantle, and a fluid core (similar to Earth).

The insulating mantle must consist mainly of molecular hydrogen (the hydrogen is transformed under pressure to a metallic phase at a depth below the visible surface of about 15% of the radius). The metallic hydrogen must have a high conductivity and this means that the whole of the interior within the boundary of the phase change is molten. If so, the solid mantle thickness may be of the order of only 10,000 km, then the explanation of the red spot motion cannot be by the interchange of angular momentum between mantle and atmosphere. However, there is still no correlation either direct or inverse, between the rotation period of the red spot and that of any other atmospheric features.

To determine the actual atmospheric structure, probes must be sent into the planet for mass spectroscopy and thermal measurements and yield the information about the general meteorological features of the planet and the presence of internal heat source.

Infrared Spectrum

Infrared spectrum observations of Jupiter were made recently from the STRATOSCOPE II (Princeton University Project), operated at 80,000 ft. Beyond 1.7μm, Jupiter tends to radiate only where the Earth's atmosphere absorbs strongly. The bands at 0.85, 0.99, 1.16, 1.37 and 1.7μm are mainly produced by CH_4. The band at 3.0μm is produced by NH_3. The broad band at 2 to 2.5μm is probably caused by the CH_4 bands at 2.20, 2.32, 2.37 and 2.42μm and also the pressure-induced dipole absorption of H_2. The nature of this band previously was hidden by terrestrial absorption.

Magnetosphere

The knowledge of Jupiter's magnetic field and magnetosphere comes from radio observations of the planet. Observations at wavelengths from 3 cm to 100 meters all indicate the existence of a magnetic field containing high-and-low-energy trapped particles. Observations at 3-cm to 3-meter wavelengths show that the radiation is about 20% linearly polarized, and that it comes from a region about three Jupiter diameters wide in the equatorial direction and one diameter in the polar direction. This radiation is continuously present, but there is a small variation in intensity as the planet rotates. This radiation is synchrotron radiation produced from relativistic electrons trapped in the region between 2 to 3 Jupiter radii. The field strength at Jupiter's surface is not well defined by these observations, but may be anywhere from a few gauss to a few tens of gauss.

The radiation from 8 meters to 100 meters does not originate as synchrotron radiation, but there is no general agreement on how it does originate. Cerenkov radiation or cyclotron radiation are the most likely candidates. The radiation is sporadic, extremely intense, and circularly polarized. This emission is most probable when the central meridian longitude is between about 180° and 360°. This immediately indicates an asymmetry; otherwise there would be a double peaked curve with the peaks 180° apart. In addition, emission probability is a function of Io's position in orbit. (Io is the innermost large satellite of Jupiter, and has a circular orbit in the equatorial plane of Jupiter, six Jupiter radii from the planet). There are two prominent peaks in emission, probability occurring when Io is near 90° and near 240°, again indicating an asymmetry; the peaks are not 180° apart. The Io effect on this emission is about 50% of the total emission when Io is at 90° $\pm 20°$ or 240° $\pm 20°$. All of the asymmetries mentioned are related to Jupiter's magnetic field, so it is assumed the field is asymmetric. It is possible that the field is dipolar with the dipole center displaced from the planet's center, or perhaps there are strong multipole components. Various studies have resulted in the conclusion that Jupiter's magnetosphere is asymmetric and there is a much greater asymmetry than exists in the Earth. The magnetosphere may extend to about 40 Jupiter radii (Earth's magnetosphere extends to 10 Earth radii).

The magnetic field of Jupiter may have a magnetohydromagnetic origin similar to that of earth. If, however, it is due to a metallic hydrogen core, it could be much more complex because of the lower viscosity and higher turbulance.

Considerable care should be taken in attempts to send probes to Jupiter, since estimates based on the strong radio signals received show that Jupiter has a considerable radiation belt. If the Jupiter surface magnetic field is about 10 gauss (based on the decameter radiation) then there must be about 10^8 electrons/cm^2-s at $E \approx 10$ MeV. (The artificial radiation belt of Earth has 10^8 electrons/cm^2-s, maximum, at $E \approx 2$ MeV) to generate the observed synchroton radiation.

The maximum electron particle flux (assumed to be at three Jupiter radii) is 10^3 times greater than the maximum flux in Earth's Van Allen belt. Observations and theories suggest the possibility of more than one radiation belt around Jupiter, also the presence of free electrons and protons.

The magnetic field strength, based on a dipole magnetic moment of 8.9×10^3 gauss/cm^3 at the surface of the planet, is approximately 60 gauss at the poles and 30 gauss at the equator.

Jupiter Satellites

The study of the satellites of a planet yields information on the planet's gross properties, including internal structure and past history. Jupiter has twelve satellites, but only four are large enough to be named: Io, Europa, Ganymede and Callisto. Two of the satellites, Io, and Europa, resemble Ganymede and Callisto; but, they are less dense and must contain a high percentage of lighter materials, probably ice and frozen ammonia over a rocky core.

Future Missions

Unmanned probes will probably be sent down into the atmosphere to measure the pressure, temperature, magnetic field, and composition of the various layers, bands, and spots. On Jupiter, atmospheric studies should be conducted to determine the percentage of H_2, He, CH_4, Ne, and Ar.

Confirmation of the latest estimate of the period of rotation (9h, 55m, 28s) and of the surface temperature (105 to 130°K) should be attempted. The NH_3 clouds in the banded structure and radiation belts in the centimeter and decameter wavelength region should be studied. Probes should also be sent out past Jupiter, where the expanding solar corona and the inter-stellar medium meet, to measure the low energy spectrum of the primary galactic cosmic rays and the extent of the inter-planetary magnetic field. The major problems in the instrumentation would be the high pressures involved.

SATURN

Saturn's size is about equal to that of Jupiter, but it has extremely low density.

Atmosphere

Absorption bands of great intensity indicate large quantities of ammonia and methane. In 1962, presence of the molecular hydrogen was discovered. This supports the assumptions that the atmosphere contains hydrogen and helium, similar to the primordial sun. There is also evidence of very high winds causing gases to be swept into the three observable bands. The bands of Saturn range in color from the broad yellowish band around the equator to the greenish caps of the poles.

Temperature

Infrared radiometric observations yield a surface temperature of 123°K. This is in close agreement with the recent black-body disk temperature of 106 ±21°K obtained from radio emissions at 3.4-cm wavelength.

Rings

The reflection spectrum of the rings appears to be very similar to that of the Martian polar cap. Therefore, it is possible that the rings are either covered by frost or made entirely of ice. The rings, along with the inner satellites, are considered to be atmospheric condensations, the reason being that rings do not form a satellite because they are within the Roche limit of Saturn.

Satellites

Saturn has nine satellites; the first five are grouped close to the planet. Mimas, Enceladus, and Tethys are probably made up largely of snow, since they are less dense than water; therefore, their surface may not be very firm. Nevertheless, Mimas can be used as an observation base, since it is close to Saturn and makes a complete orbit of the planet in less than a day. However, it has the disadvantage of Saturn's static and electromagnetic field effects on earth-bound radio signals.

Titan is the Saturn's largest satellite, comparable in size to the planet Mercury. (Titan's diameter varies from 4,200 km to 5,050 km.) Its methane atmosphere makes it unique and provides a definite source of fuel for rockets and can provide an excellent permanent refueling base.

Beyond Titan, two more satellites, Japetus and Phoebe, complete Saturn's known satellite system. These two satellites have unique characteristics: Japetus' one side is five times brighter than the other, indicating that an anomaly exists in its surface structure; Phoebe has a retrograde motion about Saturn.

Magnetic Field and Radiation Belts

The recently detected high degree of linear polarization of radio emission of Saturn at 10 meters is due to the synchrotron radiation of relativistic electrons in the radiation belt of the planet. The fact that the polarization plane is close to the axis of rotation of Saturn can be interpreted by the deformation of the magnetic field in the region of the radiation source (probably at a distance of the order of one planetary radius from the surface). The magnetic lines of force are nearly parallel to the equator due to the differential character of plasma in the planet's exosphere.

This character of rotation possibly is related to the entrainment of plasma by the particles making up the rings of Saturn. The magnetic field strength of the equatorial plane of Saturn is less than 2×10^{-3} Oe (or 200 γ). At the poles, this corresponds to a field strength of less than approximately 3×10^{-2} Oe (300 γ). The magnetic field strength in the region of the ring is assumed to be 1×10^{-3} Oe (100 γ).

Unfortunately, at present, there are no reliable data concerning the concentration and size of the structural elements of the rings of Saturn. The flux of the high energy electrons at a distance of about 0.5 to 1 (Saturn radii) from the surface is about 2×10^9 electrons/cm^2-s.

URANUS AND NEPTUNE

Uranus and Neptune are very similar in all observable characteristics. Both appear as green disks in the telescope because of the many intense absorption bands in the red region of the spectrum. They have low densities and large diameters. Neptune is slightly smaller than Uranus, but has higher density (2.7 gram/cm^3 compared to 1.56 for Uranus). Diurnal variations in the brightness of Neptune suggest two more or less antipodally situated regions of high albedo—a condition which could be due to an anomaly in Neptune's structure.

Atmosphere

The spectra of the two planets reveal large quantities of methane with a small percentage of ammonia content. However, some investigators (Kuiper) assume that there is no methane on Uranus, but a substance resembling formaldehyde. Generally, it was assumed that all of the giant planets contain large quantities of hydrogen and helium (because of their low density). The recent spectroscopic observations of Neptune and Saturn, revealed the presence of hydrogen, giving support to this assumption.

Temperature

Because of their great distance from the sun, Uranus and Neptune have average temperatures of 49°K and 90°K, respectively. As in the case of Jupiter, the surfaces of Uranus and Neptune are not visible; therefore, no data is available on surface characteristics.

Satellites

Uranus has 5 satellites that are about the size of Saturn's inner group. They technically revolve in a retrograde direction, since the equator of Uranus is inclined 98° to its orbital plane. As a result of this unusual configuration, direct line-of-sight radio communications will be possible with the Earth most of the time; however, radio wave travel time will be extended because of great distance.

Neptune has two satellites, Triton and Nereid. Triton is comparable in size with Saturn's satellites; Triton, and its surface characteristics are similar to those of Pluto.

PLUTO

Pluto was discovered in 1930 as a result of a careful search organized following a mathematical prediction of its existence. No information is available on the characteristics of this planet, except its orbital elements. The highly eccentric orbit of Pluto, brings it closer to the Sun than Neptune at perihelion and its aphelion is 40 atmospheric units from the Sun, with an inclination of 17° to the ecliptic. According to available measurements, Pluto's brightness shows a periodic variation of 0.11 mag. every 6.390 ±0.003 days. (It is assumed that this variation indicates the duration of Pluto's day). Pluto's diameter is 3,600 ±200 miles.

The 0.16 albedo of Pluto is probably due completely to surface reflection, since all the possible atmospheric components (except hydrogen) would freeze at the 45°K surface temperature. It is believed that Pluto's surface is quite rough due to collisions with meteors, comets, and the effects of its cold environment. Such basic parameters as the mass and density are more difficult to determine: since Pluto has no satellites its mass must be determined by its perturbations on Uranus and Neptune.

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