Chapter VI - The Solar System

The family of planets, with their moons or satellites, which constitute the solar system, originated in the same enormous tenuous and rotating cloud of gas, perhaps some ten million million miles across, from which the Sun was formed. As the central condensation (the Sun) grew in size a small amount of gas was squeezed out into a thin disk, and the planets finally emerged as agglomerations of the material which had collected and condensed in this disk. Fantastic temperatures of the order of 20 million degrees developed in the central blob, the Sun, as gravitational attraction compressed the primoridal gases by a factor of ten million or so, but so much less material was involved in the condensation of the planets that, in the 5000 million years since they first appeared only their innermost layers, if any, retain any fraction of their former heat. The surface temperatures of the planets and their moons are determined almost entirely by the radiation they receive from the Sun and are much too low for the emission of visible radiation. The hemisphere facing the Sun is heated to temperatures which range from about 100° to 600°C: reference to the curves of radiation from a black body (Planck's Law, Fig.   page   ) indicates that for these temperatures the maximum intensity falls in the infra red and radio regions. The Moon and the planets thus shine almost entirely by reflected sunshine, although sunshine scattered back from the Earth's atmosphere contributes a small quota to the Moon, as can be seen at times of eclipse when it glows a faint red as it lies in the Earth's shadow.

The main physical characteristics of the Moon and the planets are summarized in Table   . The planets can be seen to fall into two distinct groups. The inner group consisting of Mercury, Venus, the Earth and Mars, are of much higher density than the others and appear to be of similar composition, which must include a proportion of iron and other heavy elements to give their observed density. The outer group, Jupiter, Saturn, Uranus and Neptune, are much more massive but of lower density and obviously of quite different composition. Pluto is something of an anomaly and apparently had a different origin, possibly once as a satellite of Neptune which managed to escape.

The Moon

Thermal radio waves from the Moon were first detected in 1946, at a wavelength of 1.25 cm, by Dicke and Beringer in the U.S.A. The first measurements of its temperature from the intensity of its radio emission was made by Piddington and Minnett at the Radiophysics Laboratory in Sydney in 1948. They observed daily, at the same wavelength of 1.25 cm, throughout several complete lunar cycles of 28 days, the time taken by the Moon to complete one whole revolution. The Moon has been a satellite of the Earth for so long that, through the braking effect of the tides it causes in water masses, it has settled down to the stable condition where rotation on its own axis is completed on the same time as one revolution around the Earth. It thus always presents the same hemisphere to us, but a constantly changing aspect to the Sun, and so during the lunar month the Sun gradually rises and sets on the side of the Moon facing the Earth. Its temperature should therefore gradually rise and fall. Piddington and Minnett found that the temperature varied between about 200°K and 280°K during each , as shown in Figure 1, but that the maximum occurred 3½ days (45°) after full moon, and also after the maximum as determined from infra red measurements. This striking difference in behaviour, and the fact that the variation from maximum to minimum was only a fraction of that as found from infra red measurements, they interpreted as due to the fact that the radio waves came from below the lunar xxxx surface. Infra-red radiation is readily xx absorbed in a thin layer on the surface of rocks or similar material, whereas centimetre radio waves will penetrate several centimetres into the material. Below the surface the temperature variation is smaller because of the insulation provided by the overlying material, and lags behind the source of heat (the Sun's radiation). Support for this idea came later from

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observations made by Gibson during an eclipse which occurred in 1958, when no appreciable variation of the Moon's microwave temperature occurred. It was clear from these measurements that the Moon's surface is not solid rock, but covered with dust or similar material. It is interesting to note that actual samples of the lunar material brought back from the epoch-making flight of Apollo 11

Radio emission from the Moon has also been detected at 75 cm by Seeger in the Netherlands, at 33 cm in France, and at 21 cm by several observers. Coates in the U.S.A. and Salomonovich and Losovskii in the U.S.S.R. have carried out observations with a very narrow beam, the former at 4.3 mm in 1961 and the latter at 8 mm in 1963, which show that the temperature variation over the darker is greater than over the lighter areas.

Thixxix It is interesting to note that the best estimate of the density of the lunar atmosphere has come from a radio astronomy measurement by Elsmore at Cambridge. He found during an eclipse of the Crab Nebula by the Moon in 1956 that signals disappeared for 59.6 minutes, whereas the computed time for the Moon's disk to pass over the nebula was 59.2 minutes. The extra time taken was interpreted as due to refraction in the lunar atmosphere, whose density was deduced to be equivalent to that of the Earth at a height of about 500 km, i.e. about 2×10^{-13} of that at sea level.

The Planets

The planets are heated by radiation from the Sun and emit thermal radio waves whose intensity is determined by the temperature of the surface facing the Earth at the time of measurement. Their angular dimensions are very much smaller than the Moon, however, so they occupy a smaller fraction of the radio telescope's beam and the intensity of the emission is at a correspondingly lower level. The aerial temperature for Mars, for example, is about 0.25°K, and a sensitivity 10,000 times better than that required to detect emission from the Moon is needed. Radio waves from Mercury, Venus, Mars, Jupiter xxxxx and Saturn have now been detectdd; the only one which has emission processes of its own is Jupiter, despite the fact that its thermal emission is that of a very cold body at a temperature of about -100°C.

Mercury

Mercury is the smallest and probably the densest of the planets, and the nearest to the Sun; its maximum angular separation from the Sun is only 28° and because of this it is not an easy target for either optical or radio telescopes. It was the last of the planets to be detected by radio. Like the Moon, it is dry, without atmosphere, and tidal forces (in this case due to the Sun) have slowed its rotation to the stage where its "day" is as long as its "year", each being equal to 88 Earth days. One face is thus subject to continuous heating from the Sun, and infra-red measurements of the surface temperature of the sunlit hemisphere (made by Pettit and Nicholson at Mount Wilson) yield a figure of 613°K, i.e. more than enough to melt lead!

Radio emission from Mercury was first detected in 1961 by Howard, Barrett and Haddock of the University of Michigan: the observed aerial temperature was only 0.05°, from which they deduced a black-body temperature of approximately 400°K.

Venus

Despite the fact that Venus is the planet which most closely resembles the Earth in size and mass, and comes nearer to us than any of the others, the state of its surface and composition of its atmosphere are still subject to conjecture. This is primarily because optical telescopes have not been able to penetrate the dense and almost featureless cloud layers which perpetually hide what exists beneath. Lying as it does between us and the Sun it shows phases like the Moon but at its closest approach, at inferior conjunction when it is between Earth and the Sun, its dark side is presented to us. We see it fully illuminated at superior conjunction, but by that time it is some six times as far away and a correspondingly smaller target.

Spectrographic analysis of its light shows that the Venusian atmosphere consists predominantly of carbon dioxide with perhaps a trace of water at the highest levels, but no oxygen has been detected. The presence of substantial amounts of water and oxygen in the Earth's atmosphere, however, makes it difficult to detect very small quantities of these substances in external bodies. Temperature measurements by the usual infra-red methods give a figure of 234°K ~~x~~ (-39°C), but this refers to the level in the upper atmosphere where the infra-red wavelengths are ~~xkmxx~~ absorbed. The temperature at the top of the cloud layer is estimated to be about 285°K (12°C), ~~fxm~~ from an analysis of the visible spectrum, but no information about conditions on or near the surface was available until radio methods were introduced. Venus, in fact, was the first planet whose temperature was estimated in this way, when Mayer, McCullough and Sloanaker at the Naval Research Laboratory in Washington, D.C. detected its radio emission at a wavelength of 3.15 cm on 2nd May, 1956. The value they obtained - about 600°K - was much hotter than expected and finally disposed of the possibility of finding life on the planet. Since then radio emission has been measured at wavelengths from 21cm down to a few millimetres: from about 3 cm upwards it is equivalent to that from a black body at a temperature of about 620°K (or 350°C) and the indications are that this represents that of the surface of Venus. Venus is closer to the Sun than the Earth but not by enough to account for a surface temperature more than double that to which we are accustomed. One explanation for this is that the atmosphere is relatively transparent to incoming solar radiation but opaque to the longer wavelength radiation from the heated surface, and so exerts an effect similar to the glass of a greenhouse.

The intensity of Venus' radio emission is some 30 times greater at its closest approach and most of the measurements have been made around that time, i.e. when most of the surface facing us appears dark. An extended series of measurements to investigate whether a phase effect similar to that of the Moon was also present on Venus was made recently by Mayer, McCullough and Sloanaker, using a wavelength of 3.15 cm. They found that the equivalent black body temperature varied from about 730°K for the illuminated hemisphere to 550°K for the dark side, and also that the minimum temperature occurred about 12° after inferior conjunction. One interpretation of this is that Venus is rotating in a retrograde direction, i.e. opposite to that of other planets: there is no information at all from optical observations which bears on the rotation period of Venus, but recent radar observations (see Chapter) support the retrograde rotation. Observations of temperature variations at maximum are more difficult to make because of weaker signals from Venus, and proximity to the Sun.

Mars

Mars, the red planet, has always been of popular interest because of recurrent speculation that it may be inhabited. This possibility arose from the reputed appearance by keen visual observers, particularly the American Percival Lowell, of a network of intersecting lines on the surface of the planet at times which corresponded to the melting of polar ice caps. They were interpreted as canals, the inference being that they had been dug by intelligent beings to make the most of the limited amount of water on Mars. Despite further such reports by visual observers from time to time the canals consistently failed to appear in photographs taken with large telescopes, and the legend of intelligent beings has gradually died, although the possibility of lower forms of life has not been ruled out. Mars is also of particular interest because it is the only one of the planets - apart from Mercury, which, however, is too close to the Sun - whose atmosphere is transparent enough to allow us to detect surface markings. There is no doubt about the reality of the polar ice caps, which consist predominantly of dry ice (frozen carbon dioxide) rather than water ice. Our most detailed information about its atmosphere and surface characteristics have come from the U.S. series of instrumented spacecraft, particularly Mariner 5 and 6, which passed within 2000 mimi miles of the planet in July-August, 1969 and relayed television pictures and instrumental readings. These have kimmiix finally

Thermal radio emission from Mars at a wavelength of 3 cm was first detected at a close approach in 1956 by Mayer, McCullough and Sloanaker. More accurate measurements at 3 cm by Giordmaine, Alsop, Townes and Mayer in 1958 gave a black body temperature of about $210^{o}K$. The value derived from infra-red measurements is about $250^{o}K$ for the sunlit side, so the radio emission originates below the surface, as for the Moon. This is in line with photographs of the Martian surface obtained during the Mariner series of flights, which imdmx indicate a landscape closely resembling that of the Moon.

Jupiter

Jupiter is by far the most massive of the planets, and accounts for over 70% of the total mass of the planetary system: it is also the largest. Its mass is about 318 times and its diameter 11 times that of the Earth, but its average density is only about one-quarter of ours. Its composition, therefore, is clearly very different: to account for a density of 1.35 gm/cm^3 it must consist predominantly of the light gases hydrogen and helium, with perhaps a small core containing heavier elements.

In keeping with its greater distance from the Sun it is cold: infra-red measurements indicate about 140°K (-133°C). In its chilly atmosphere some relatively permanent markings can be distinguished, in particular "the great red spot", three "white spots", which are oval in shape, and a "south tropical disturbance", which was present for a number of years but disappeared in 1939. These are presumably variations of the clouds of unknown composition which exist in the Jovian atmosphere and completely hide what lies below. Keen visual observers have watched the panorama of visual markings for years: they indicate that the huge planet completes its day in less than ten hours, but the period of rotation derived in this way varies slightly from equatorial regions to higher latitudes, indicating that the markings are not those of a solid surface but of streaming motions in its atmosphere. Astronomers have defined two rotation systems for Jupiter: "System I" applies to equatorial regions with a period of $9^h50^m30^s.003$, and "System II" for the rest of the planet, with a period of xxxxxxxxx $9^h55^m40^s.632$. Spectrographic studies indicate that hydrogen and helium constitute the bulk of Jupiter's atmosphere, but that the gases ammonia and methane are present in fairly large quantities above the cloud layer.

The story of Jupiter's radio emission opened dramatically in 1955 with a report from Burke and Franklin of the Carnegie Institute of Washington that it was emitting short bursts of radio waves of considerable but fluctuating intensity. The signals sounded very much like the sharp bursts of static from thunderstorms that are sometimes heard on short-wave circuits. The discovery was, in fact, quite accidental. Burke and Franklin xx were trying out a new Mills Cross type of aerial designed for working at the long wavelength of 15 metres (22xxx (22.2 MHz), and had directed it towards declination 23°N. so that two well known sources, the Crab Nebula and another bright nebula, IC 443, xxxxxxxxxxxxx would pass through the beam. Amongst a multitude of signals recorded over a period of se several months were some which had all the characteristics of car ignition or similar interference, but appeared only for a few minutes each day, when no known source of interfering signals was present. Burke and Franklin checked the apparent movement of the source in the sky and, to their great astonishment, found that it coincided exactly with that of the planet Jupiter. The scepticism of other radio astronomers was soon dispelled when they turned their radio telescopes on this unexpected source - provided they chose an appropriate wavelength, because another surprising fact emerged in that the bursts of emission were confined to a relatively narrow range of wavelengths, from about 10 to 20 metres (15-30 MHz).

The first to confirm the news of Jupiter's strnge emission was C.A. Shain of the Radiophysics Laboratory in Sydney. Some five years earlier Shain had constructed a long-wave version of the Mills Cross on the outskirts of Sydney and carried out a sky survey at a wavelength of 16.4 metres (18.3 MHz). Checking through records obtained in 1950 and 1951 he found many series of bursts which, at the time, had been attributed to terrestrial interference but which had undoubtedly come from Jupiter. Their duration was of the order of two hours, and from his recordings of them over a period of nearly two years Shain was able to show that they originated in one or more localized areas on Jupiter, rather than from the planet as a whole, and that they had a rotation period which differed from any that had been observed. Some examples of Jupiter's bursts on Shain's records are shown in Figure 2. At first it was thought that they might coincide with some of the visible markings, e.g. the great red spot, but the period differs slightly from those of all the visible features and is apparently associated with that of the solid body or, as we shall see below, of its magnetic field.

Thermal emission from Jupiter was first detected in 1956 by Mayer, McCullough and Sloanaker on a wavelength of 3 cm. Its black-body temperature is about 145°K, which agrees well with the infra-red value and probably refers to that of the cloud with which the planet is covered.

Observations at longer centimetre wavelengths, however, disclosed further anomalous behaviour on the part of Jupiter: the intensity was very much greater than would be expected from a black body at 145°K (for example, about 2000°K at 21 cm and 5000°K at 3 cm) and the radiation was partly linearly polarized. Both observations suggested origin in a non-thermal process. Measurements made with an interferometer by Radhakrishnan and Roberts at the California Institute of Technology showed that at a wavelength of 31 cm the radio emission comes from an area which is some three times that of the visible disk of Jupiter. Roberts and Komesaroff obtained similar results when they observed an occultation of the planet by the Moon using the 210 ft radio telescope at Parkes: the radiation began to decrease before the Moon's edge reached the visible planet and continued to decrease for some time after the disk was fully obscured, indicating origin in an invisible halo. They also noticed that the radio waves are linearly polarized and that the plane of polarization "rocks" through an angle of about ±10° as the planet rotates (Fig. 3).

Studies of the metre wave bursts, in particular by Douglas and Smith, show that the probability of occurrence is high for three longitude regions on Jupiter. Slee and Higgins in Australia used an interferometer with a baseline first 60 and later 120 miles long and showed that the bursts came from an area about one-tenth the size of the planet. Detailed studies of burst structure by Kraus at the Ohio State University and by Warwick and Dulk at Boulder revealed that the individual pulses within bursts are generally of duration about one second, but occasionally contain components of milliseconds duration. The average amplitude shows a small variation throughout the sunspot cycle but with an inverse correlation with sunspots. Several observers have reported what appears to be a triggering action by very large flares: increased activity was noted some 3-5 days after these events, the delay being attributed to the time taken for the solar plasma to reach Jupiter.

The radio emission spectrum of Jupiter thus consists of three distinct components:-

(i) Thermal emission from the visible disk: this is observed alone at wavelengths of 3 cm and below.

(ii) Non-thermal radiation with synchrotron characteristics at decimetre wavelengths (10-100 cm).

(iii) Intense bursts of short duration at metre wavelengths.

The non-thermal emission receives a ready explanation if the planet is surrounded by a "Van Allen" belt similar to that which satellite observations show surrounds the Earth. Within this belt electrons moving at relativistic speeds are confined by Jupiter's magnetic field and radiate strongly by the synchrotron process. The arrangement of this belt in relation to Jupiter's axis is shown in Figure 4: the electrons in this belt must be more numerous and more energetic than those in the Earth's Van Allen belt. The magnetic axis of Jupiter (and hence the radiation belt) is apparently inclined at an angle of 10^{o} to the rotational axis, and this produces the observed rocking of the plane of polarization as the planet rotates. The intense burst activity is probably caused by a discharge of electrons from the belt to the surface of the planet, set off by some particular feature of the magnetic field, and channelled in a narrow beam towards a particular spot or spots on Jupiter. These discharges are probably of short duration, and simultaneous recordings taken up to 10^5 or more wavelengths apart show good correlation for time scales of much less than a second. The typical longer duration features of bursts, however, show no such correlation at spaced sites and indicate that their origin is in the scintillations produced by solar plasma: similar patterns are sometimes recognizable but spaced in time, and the velocity of the plasma deduced in this way (500 km/sec) is reasonable.

An ~~intensity~~ interesting discovery in relation to the periodicity of the metre-wave bursts was made in 1964 by E.K. Bigg of the Radiophysics Laboratory in Sydney. Bigg plotted burst activity in relation to orbital position of Io, Jupiter's innermost satellite,and found that the occurrence of bursts was intimately related to Io's position. Burst activity is very high for only two positions of Io in its orbit, as illustrated in Figure 5. It thus seems that Io, a body the size of the Moon, produces a distrubance in Jupiter's magnetosphere which in some way we do not understand at present, facilitates a discharge from the charged belt to the planet itself.

Bigg has recently discovered other periodicities in the intensity of ~~the~~ burst emission from ~~Ju~~ Jupiter, one of which coincides within five seconds of ~~the~~ the period of a yet undiscovered satellite whose existence is postulated by Bowell and Wilson. It thus provides some confirmation of the latter's predictions, but it is difficult to see how this (hypothetically) much smaller body at a greater distance from the planet could exert any such ~~ef~~ effect.

Saturn

Saturn, in spite of its unique system of rings, is probably rather similar to Jupiter, but its average density is lower- in fact less than that of water - so that, theoretically in a suitable environment it would float! Its surface, like that of Jupiter, is hidden by permanent cloud layers which are also drawn out into belts as a result of the rapid rotation of the planet, but distinctive spots or other markings appear only rarely.

The famous system of rings that make Saturn such a fine sight in a small telescope consists of a very large number of small particles rotating in orbits which are confined to a very thin region on the orbital plane of the planet - estimated to be of the order of only 1 km thick compared with their diameter of nearly 300,000 km. Saturn possesses nine moons and it seems probable that the ring system represents the material for a tenth moon which somehow did not condense.

Radio emission at 3.75 cm was first detected by Drake and Ewen in 1957. Measurements made on 3.4 cm at the University of Michigan in 1960 gave a brightness temperature of 106°K: this was based on the assumption that no contribution came from the rings, and the temperature would be lower if these were also emitting. Pettit and others using infra red methods found a temperature of about 125°K, but the difference between this and the radio method is less than the possible xxxxx errors in the measurements. There have been several reports of what may possibly be bursts from Saturn, similar to but much weaker than those from Jupiter, but this has not been confirmed.

The Other Planets

The remaining two of the giant planets, Uranus and Neptune, are so much further away that the intensity of their thermal emission is down by a factor of more than 10 on that from the last planet to be detected, Mercury. They are poor optical targets too and telescopes provide little detail about them - they were both recorded many times as stars before Herschel in 1781 discovered that Uranus was a planet! Infra-red measurements indicate a temperature of about 90°K for Uranus and Neptune is probably below 80°K. Detection of thermal emission from bodies as cold and as distant will require the use of a large radio telescope capable of effective use at short centimetre wavelengths.

Pluto was discovered from the slight perturbation it causes to the orbit of Neptune. It is indistinguishable from a star-like image in all but a few of the world's giant optical telescopes and little is known about it. The next 30-40 years will provide better conditions for studying Pluto than at any time since its discovery because its closest approach to Earth occurs in 1989. Even then, however, it will be almost as far away as Neptune.

There is little information about the radio emission of those transitory members of the solar system, the comets, which spend so much of their time at enormous distances from the Sun, since there have been no outstanding appearances since the birth of radio astronomy. Some excitement was occasioned in 1957, however, when W Kraus at Ohio State University and Contrez and his associates in Belgium reported radio emission from the bright comet rend-Roland: other radio astronomers, however, failed to detect any signals from it.

TABLE

CHARACTERISTICS OF THE PLANETS

	Mean Distance from Sun		Diameter	Density	Mass	Length of Day	Length of Year	Temperature		λ
	Miles	A.U.	10^3 miles					Radio (°K)	Infra-Red	cm
Mercury	36	0.39	3.1	4.5-5.0	0.05	88^d?	88^d	400	610	3
Venus	67	0.72	7.7	4.9	0.81	250^d	224.7^d	700-550 500	370 250	3-10
Earth	93	1.00	7.9	5.5	1.00	1^d	365.26^d	-	287 av.	
Moon			2.2	3.3	.012			280-145	375-150	1
Mars	142	1.52	4.2	4.0-4.2	0.11	1^d37^m	687^d	210	250 217	3
Jupiter	482	5.20	88	1.4	318.4	9^h55^m	11.9^y	145 600	140	3 10
Saturn	880	9.5	75	0.7	95.3	10^h38^m	29.5^y	106±21 140-213	125	3 9
Uranus	1780	19.2	30	1.6	14.6	10^h42^m	84.0^y	-	90	
Neptune	2800	30.1	27	2.5	17.3	15^h48^m	164.8^y	-	(75)	
Pluto	3700	39.5	75?			?	247.7^h	-	(50?)	