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CURRENT PROBLEMS IN RESEARCH

Atmospheres of Other Planets

Much has recently been discovered about the atmospheres of the planets, but some puzzles remain.

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The study of planetary atmospheres requires the joint efforts of scientists from many fields. Since the data must be gathered largely by telescopic means, astronomers play a dominant role. However, a cool planetary atmosphere with a solid surface below and clouds within is by no means so simple an object for study as a very hot, completely gaseous star. The methods of astrophysics, however successful with stellar and nebular problems, are not often adequate here. The history of serious planetary study is therefore marked by contributions, albeit too infrequent, from chemists, physicists, meteorologists, and biologists.

Although there are eight other known planets in our system, there is no need to discuss all of them here. Mercury is essentially devoid of atmosphere; Saturn, Uranus, and Neptune so closely resemble Jupiter that we need discuss only the latter; and Pluto is so distant that virtually nothing is known of its atmosphere. I shall, therefore, deal only with Venus, Mars, and Jupiter. We shall see that physical conditions and the nature of the atmospheres of these three vary so greatly that each represents a unique scientific puzzle. Some of the pertinent physical data on these planets are given in Table 1.

Venus

Telescopic study of Venus is complicated by that planet's position between our orbit and the sun. When Venus is closest to Earth, and therefore presents its maximum angular diameter, most of the planet is in shadow and only a thin illuminated crescent can actually be seen. When Venus is on the opposite side of the sun from us we have the advantage of seeing the full phase, but then the angular diameter is small because of the great distance of the planet. This unfortunate situation is only the first of several frustrating facts which make the study of Venus difficult.

That Venus has an atmosphere was known long before any spectroscopic evidence of the composition of its atmosphere was produced. In the absence of an atmosphere it is possible to calculate the extent of the thin crescent phase from purely geometrical and astronomical considerations. Direct observation shows clearly that the illuminated crescent of Venus, unlike that of our moon, extends much further than one would expect. Figure 1 shows a direct photograph in which the crescent of light extends around the planet to form a complete ring. This can only be due to refraction and scattering in an atmosphere.

Aside from mere speculation, nothing was known of the composition of this atmosphere until 1932, when Adams and Dunham (*1*) of the Mount Wilson Observatory recorded the spectrum of Venus near 8000 angstroms, using high dispersion and a new fast photographic emulsion. They recorded two new absorption bands, with heads at 7820.2 and 7882.9 angstroms and detectable line structure. Since virtually no laboratory spectra of common gases had been recorded then in this part of the spectrum, it was not possible to identify the responsible gas by direct comparison. Instead, Adams and Dunham measured the positions of the constituent lines of the bands and calculated the required moment of inertia of the unknown molecule. The result agreed closely with the known value for CO_2. To complete the identification, Adams and Dunham set up a long metal pipe, sealed with glass windows at the ends, and then filled the pipe with CO_2 at high pressure. The spectrum of light passing through this massive amount of gas exhibited an absorption band at the same wavelength as one of those observed for Venus, thus completing the identification. This must surely be regarded as a notable and elegant combination of theory and experiment to achieve scientific truth.

Herzberg (*2*) has studied these absorptions of CO_2 in the laboratory, using a multiple-reflection absorption tube which permits very long effective path-lengths with low pressure. This is important since the bands involved vary in intensity with pressure even when the total amount of gas in the path is kept constant. Herzberg found that the strength of the planetary absorption is matched in the laboratory by that of a column of CO_2 1000 meters long at a pressure of 760 millimeters of mercury and a temperature of 0°C. Since the Earth has but 2 meter-atmospheres of CO_2, the amount on Venus is 500 times larger than our own.

No other gases have been identified positively in the atmosphere of Venus. Adams and Dunham have searched for O_2 and H_2O absorptions at a time when the relative radial velocity of Venus and Earth was large. Because of the Doppler effect, the Venusian lines are then shifted slightly from the positions of the terrestrial lines and may be detected despite the interference of the Earth's oxygen and water vapor. Visual inspection of

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these spectrograms revealed no noticeable absorptions by the atmosphere of Venus, and Adams and Dunham estimated that the planet has less than 5 percent of the terrestrial amount of these gases. This limit can be refined much further, and possibly a positive identification may be obtained, if such high-dispersion spectra are measured photometrically for asymmetries in the terrestrial line profiles. Such asymmetries will be produced by relating small amounts of O_2 and H_2O whose absorptions have been displaced by the Doppler shift. This matter cannot be considered closed.

Emission features in the spectrum of the dark side of Venus have been recorded (*3*) which coincide with the positions of known bands of the singly ionized nitrogen molecule in the airglow of our own night sky. These emissions are more intense than those from our own night sky and strongly imply the existence of appreciable amounts of nitrogen on Venus. The question has been raised (*4*) whether this is not due to scattering of light from Venus by the N^+_2 in our own upper air. Furthermore, other molecules may emit at similar wavelengths. These doubts will have to be resolved, and the observation will have to be verified before its implications can be accepted without reservation.

Thermal Data for Venus

Temperatures have been determined by a variety of means. From a measurement of the infrared energy arriving from the planet it is possible to calculate the temperature of a black body which would emit at this rate. Three independent sets of such radiometric estimates (*5*) agree that the radiometric temperature is near −38°C for both the dark and sunlit parts of Venus. This is surprisingly low compared with terrestrial temperatures and remarkably independent of night and day. The presence of large amounts of CO_2 permits us to understand these results because a large proportion of the infrared energy from the visible surface (around 10 microns and 13 microns) cannot escape to space but is absorbed by the overlying CO_2 and re-emitted at a rate determined by the temperature of the overlying atmospheric layers. Thus, −38°C applies to some layer relatively high in the atmosphere of Venus, not to the surface. From terrestrial experience, we expect the upper atmosphere to have a smaller diurnal temperature variation than the surface, but even so the diurnal uniformity of the radiometric temperature implies a vigorous convective circulation which transports large amounts of heat from the day to the night hemisphere.

The photographic infrared bands of CO_2 (around 0.8 micron) are intrinsically weak and require large amounts of the gas for their development. As a result, these absorptions take place primarily in the dense lower atmosphere, in contrast to the strong radiometric emission bands which are developed at a higher level. The envelopes of the photographic bands are due to vibrational transitions, while the line structure of each band is the result of rotational transitions in the CO_2 molecule. But the populations of the various rotational energy levels are determined by the gas temperature, so it is possible to estimate the temperature of the absorbing layer from the distribution of intensity among the lines. Adel's original calculations (*6*) based on this idea gave a temperature greater than 50°C. Subsequent investigators have found values ranging from 16° to 27°C, with an uncertainty of tens of degrees. These results are definitely higher than the radiometric values and lend support to the idea expressed above that temperature decreases with height in the atmosphere of Venus, as it does in the major part of the Earth's atmosphere, and that the 10-micron radiation is largely from CO_2 at a high level.

Very recently (*7*) the intensity of radiation at a wavelength of 3.15 centimeters has been measured by radio techniques. A black-body temperature of about 300°C was obtained, on the assumption that this, too, is thermally excited. The uncertainty is near 100°C. Even if the figure of 300° is reduced to 200°C, it is still much higher than the earlier values. This difference may be because such long waves can originate below the visible surface and because part of the energy may be produced electrically rather than thermally.

We never see the solid surface of Venus, only a continuous cloud cover. This is responsible for the high albedo and for the absence of permanent surface markings. Lyot (*8*) has made careful studies of the polarization of the reflected sunlight as a function of the difference between the angle of illumination and the angle of view. He finds that the polarization curve for Venus resembles that of water droplets of diameter 2.5 microns. However, this is not a definitive identification, since polarization depends upon particle size and wavelength as well as upon composition. Measurements at several widely separated wavelengths are clearly needed.

Indeed, the thermal data clearly indicate that the clouds cannot be H_2O, for at such high temperatures the amount of vapor in equilibrium with the clouds could be detected spectrographically. Some have assigned the −38°C radiometric result to the cloud surface. In this case the clouds would be ice particles, and the small amount of vapor in equilibrium with them would go undetected. As we have seen, however, the visible surface must be much warmer than this.

Composition of Clouds on Venus

Speculations about the cloud composition have included the following: (i) dust as the principal component; (ii) the now disproved hypothesis of formaldehyde polymers; and (iii) the recent untested postulation of polymers of carbon suboxide (*4*). This is a very open field for research, in which the definitive solution may well come from a physical chemist who is willing to study the complex reactions of CO_2 under the influence of ultraviolet light (*9*).

Table 1. Salient physical data for selected planets compared with data for Earth.

	Earth	Venus	Mars	Jupiter
Mean distance from sun (Earth = 1)	1.00	0.72	1.52	5.20
Diameter (Earth = 1)	1.00	0.96	0.53	11.0
Mean density (g/cm³)	5.52	5.06	4.12	1.35
Period of revolution about the sun (yr)	1.000	0.6152	1.8808	11.862
Axial rotation period	23^h56^m	?	24^h37^m	9^h50^m–9^h56^m
Inclination of equator to orbital plane	23°27′	?	25°12′	3°07′
Surface gravity (Earth = 1)	1.00	0.86	0.37	2.64
Approximate mean temperature of "visible" surface in sunlight (°C)	+10	+50–+100	−10	−120
Albedo	0.36	0.59	0.15	0.44–0.51

Since we do not see a solid surface it is impossible to determine the axial rotation period by observing the motion of surface features, as we do for Mars. Definite spectrographic evidence exists that the period must be greater than about three weeks. In 1928 Ross (*10*) discovered that ultraviolet photographs of Venus disclosed large light and dark shadings which are variable in form and duration. These ultraviolet markings are poorly understood. Recently Kuiper and Richardson have separately noted periods of preferred orientation of these features. They assume that these features represent convection currents from the sunlit to the dark hemisphere. This would put the markings parallel to the equator and permit calculation of the orientation in space of the pole of rotation. Unfortunately, the two separate determinations of this orientation disagree by a large angle, making the method suspect.

The infrared radiation from Venus' CO_2 is highly variable in amount. Since the atmosphere cannot cool enough from day to day to account for this, it is likely that a second, higher cloud layer forms intermittently to block this radiation, or that the primary cloud surface sometimes is lifted much higher by convection. The relationship between this phenomenon and the ultraviolet markings has never been investigated.

The high temperature of the surface and the scarcity of H_2O and O_2 makes it highly unlikely that life as we know it can exist on Venus.

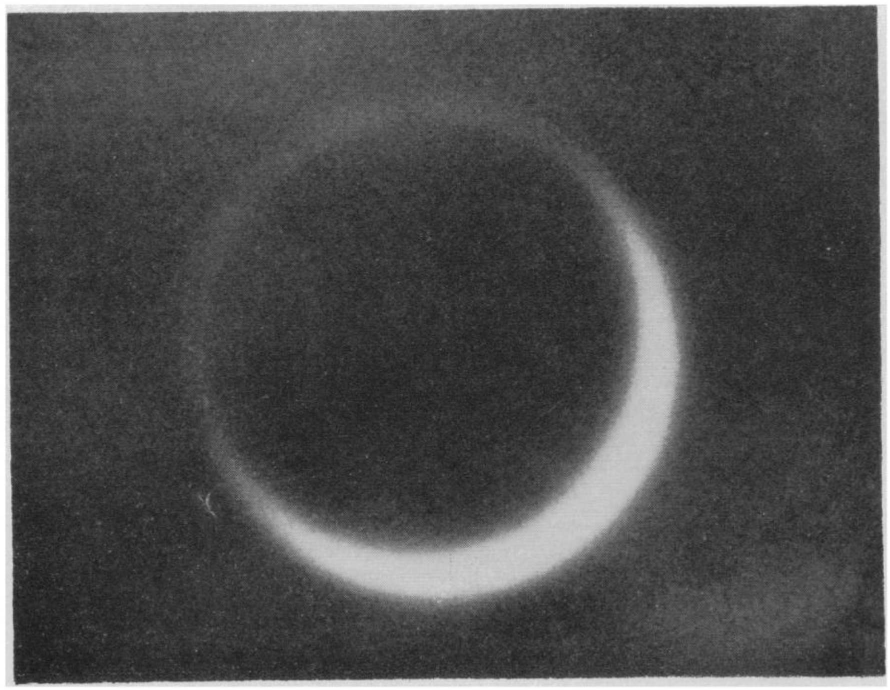

Fig. 1. Photograph of Venus taken in red light when the planet was between the Earth and the sun, showing a complete ring of light encircling the dark disc of the planet. Venus was then 2¾° from the sun. [Photograph by E. C. Slipher and J. B. Edson of the Lowell Observatory]

Mars

Mars is the nearest planet whose orbit lies outside that of Earth. Thus, when Earth and Mars are closest together we see a fully illuminated planet, in contrast to the quite different situation for Venus. Despite the fact that Mars is smaller than Venus and cannot come as close, the geometry of the orbits of Earth and Mars makes Mars the planet which we can subject to the most detailed telescopic examination.

Perhaps the first evidence that Mars has an atmosphere came from the occasional presence of clouds. In contrast to Venus, Mars' solid surface is usually exposed to visual examination and is only sometimes partly obscured by clouds. These must be supported by an atmosphere. The only constituent which has been positively identified spectrographically is CO_2. This was discovered by Kuiper, in 1948, by means of the 1.6-micron absorption bands; he used an infrared spectrometer with a lead sulfide photoconductive cell as the sensing element. Kuiper (*11*) originally estimated that there is twice as much CO_2 per unit area on Mars as on Earth. However, calculations have been published in which the effect of the interplay of the Martian and telluric lines of the band has been taken into account. These indicate that there is about ten times as much of the gas on Mars as on Earth.

The existence of water vapor in the atmosphere has long been suspected because of the easily seen white polar caps, which wax and wane with the Martian seasons. This assumption was greatly strengthened when Kuiper used the infrared spectrometer to show that the polar caps have the same decrease in reflectivity at 1.5 microns which snow exhibits in the laboratory. Since the caps are H_2O snow, there must be some of the vapor in the atmosphere. Nevertheless, carefully conducted spectrographic tests, in which very high resolution and the Doppler shift method of disentangling the planetary and terrestrial lines were used, have failed to reveal positive evidence for H_2O vapor. The spectrographic records have never been measured for asymmetries of the lines, so we cannot state a firm upper limit for the amount of H_2O, but if all the Martian vapor were condensed to liquid, it probably would not occupy a layer more than a small fraction of a millimeter thick. The Martian atmosphere is surely extremely arid. No bodies of liquid H_2O could last long in such a dry atmosphere, so there are no lakes, rivers, or oceans on Mars.

Argon is very probably present. All terrestrial argon was produced by decay of radioactive potassium-40. If we assume that the crust of Mars has the same proportion of K^{40} as that of Earth, there should be about 13 grams of argon per square centimeter of the planet's surface.

Various methods, mostly optical, have been used to determine the total amount of Martian atmosphere (*12*). The measurements are difficult to make, but it is probable that the surface pressure is 50 to 100 millibars. This is to be contrasted with normal terrestrial sea-level pressure of slightly more than 1000 millibars. Of course, gravity on Mars is only 0.37 of ours, so the mass of atmosphere per unit area is evidently between one-eighth and one-third of our own. The gases already discussed do not amount to this much, and nitrogen is thought to constitute the bulk of the atmosphere. The absorptions of nitrogen are all in the portion of the ultraviolet to which our atmosphere is opaque, so no direct spectrographic evidence is available to support this idea. Such data might be obtained by means of a rocket.

Temperature Distributions on Mars

Temperature distributions over the face of the planet have been determined radiometrically (*13*). When the sun is directly overhead, the surface temperature may rise as high as +30°C. The temperature decreases towards the poles at a rapid rate in the winter hemisphere and less rapidly in the summer hemisphere, as would be expected. The small summer polar cap has a temperature somewhat below 0°C, and the most poleward latitude measurable in the winter hemisphere, one of about −60°C. We do not know the nighttime minimum temperatures, but it has been estimated that even at the equator they may fall as low as −100°C. Certainly, the diurnal range of temperature exceeds anything we experience on Earth. This is primarily due to the great dryness of the Martian atmosphere, which cannot provide a strong "greenhouse" effect.

The radiometric data apply to areas of the planet that are small enough to permit the temperatures to be plotted on a map and analyzed in very much the same way that terrestrial meteorological temperatures are plotted and analyzed. The Martian temperature maps are qualitatively similar to terrestrial ones. Since there is a well-known link between temperature and pressure gradients and, on rotating planets, between pressure gradients and wind, there is reason to believe that Mars has a general atmospheric circulation similar to that of the Earth. Therefore, the detailed study of this circulation is a matter of potentially great interest to meteorologists. As we shall see, however, it is not easy to gather detailed circulation data for Mars.

Martian Clouds

Martian clouds may be divided into two main classes: the occasional and ephemeral ones, which can be detected visually or photographed in yellow or red light and the persistent, widespread clouds observable on photographs in blue light, called "blue haze." Most of the visible clouds are observed near the morning and afternoon limbs and are presumably due to low-level condensation of the meager water vapor at the low temperature of those places. Thin ice fogs are probably common during the very cold Martian night. White and yellowish clouds are sometimes seen closer to the center of the planetary disc. These may be due to high-level convective condensation of water vapor (white clouds) and dust storms (yellowish clouds). The only way the atmospheric circulation may be studied is by observing the drift of these visible clouds. Unfortunately, the clouds move too slowly to permit reliable measurement of the motion in a few hours, and they are so ephemeral that the same cloud is rarely observable on successive nights. A preliminary attempt (*14*) to study the existing data suggested great similarity to terrestrial circulation, even as to details. However, this result needs to be extended and verified. I am in the process of assembling and studying the Martian cloud data gathered by a global chain of observers during the close approach of Mars in 1956.

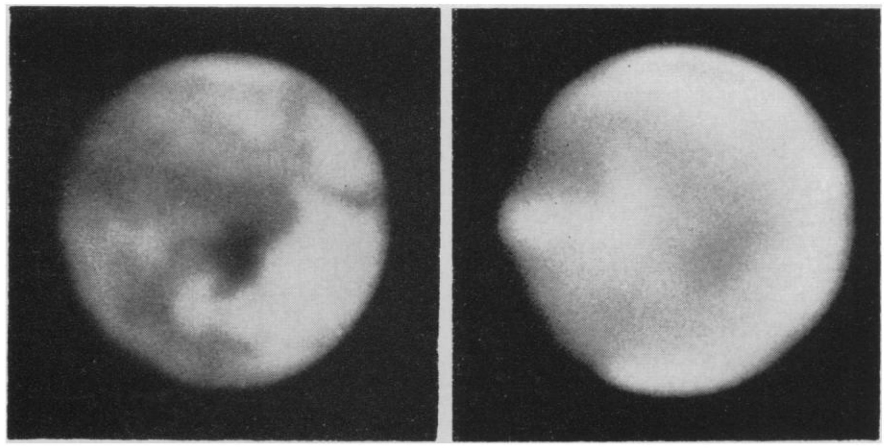

Fig. 2. Two photographs of Mars taken in red and blue light, respectively, on the same night (11 June 1954). The dark Syrtis Major and other well-known Martian surface features show clearly in the red-light photograph (left) but are obscured in the blue-light photograph (right). [Photographs by E. C. Slipher and A. P. Fitzgerald of the Lowell Observatory–National Geographic Society Expedition to the Lamont-Hussey Observatory, Bloemfontein, Union of South Africa]

The blue haze is of great scientific interest. Figure 2 shows a photograph of the planet, taken in red light, in which surface features are easily seen, and a photograph of the same face of the planet, taken in blue light, in which the haze completely obscures all surface features. This haze is relatively thin; it suffices to obscure the dark Martian markings, which do not have high contrast against the lighter areas, but often does not suffice to conceal the more contrasty polar caps. On occasion the haze clears away and permits the surface detail to show through. Such behavior means that this is an atmospheric phenomenon. There is reason to believe (*15*) that the blue haze consists of a layer of H_2O ice crystals a few kilometers thick at an elevation of 30 to 35 kilometers above the surface, near the Martian tropopause. When warming occurs at these levels, as it will sporadically, the haze evaporates partially and the surface can be photographed in blue light. From polarization data it appears that the ice particles have a mean radius of about 0.2 micron.

In the absence of O_2 and of appreciable amounts of H_2O, animal life similar to that on Earth cannot exist. However, the existence of bacterial and elementary plant life is not an impossibility (*16*). The dark areas of Mars, which increase in size and contrast during summer and weaken in winter, have long been thought to be caused by a form of vegetation. Sinton (*17*) has found evidence for absorption due to the fundamental vibration of the C—H bond at 3.45 microns in the reflection spectrum of Mars. Such a demonstration of the existence of organic molecules at the surface is of great importance and should be repeated and verified.

Jupiter

Jupiter, like Venus, is completely covered with clouds, but the cloud surface is not essentially featureless, as it is on Venus; it exhibits a large array of dark belts and light zones, spots of various sizes and colors, and wisps of cloud material. The telescopic appearance of Jupiter is shown in Fig. 3. Most of these cloud features are persistent. Many of the spots can be followed for months, with the result that accurate rotation periods can be determined. These periods indicate that the visible features are not all rotating at the same rate. This, together with changes in appearance from time to time, indicates that we are dealing with a cloud surface and, therefore, with a planetary atmosphere.

It has been known since the 1860's that the spectrum of Jupiter exhibits band absorption in the red. With virtually every extension of the sensitivity of photographic emulsions into the infrared, more such absorptions were discovered. For a long time the gases causing these bands remained unidentified, until, in 1932, Rupert Wildt, then a physical chemist but now an astrophysicist, pointed out that CH_4 and NH_3 had known absorptions at some of these same wavelengths. Experimental spectra of methane and ammonia in the laboratory were soon obtained which verified this suggestion and established that these gases are constituents of the Jovian atmosphere. We now know that above the cloud surface there is an amount of methane equivalent to 150 meters of the gas at a pressure of 760 millimeters of mercury and a temperature of 0°C and an amount of ammonia equivalent to 7 meters under the same conditions.

We have indirect evidence that the atmosphere must consist largely of H_2 and He, with CH_4 and NH_3 as minor constituents. The argument is this: The oblateness of a planet depends not only upon its rotation rate and surface gravity but upon the distribution of density from the center outward. The oblateness, gravity, and rotation rate for Jupiter indicate a high degree of concentration of mass near the planet's center. Thus, the outer layers must have a density less than the over-all mean density, which is only 1.35 grams per cubic centimeter. The only way in which a sufficiently low density can be obtained for the outermost layer is for the atmosphere to be quite deep (to extend well below the visible upper surface of the clouds) and to be composed predominantly of the lightest gases known—namely, hydrogen and helium. Similar arguments can be made for Jupiter's fellow planets, Saturn, Uranus, and Neptune.

Under normal conditions, H_2 and He do not absorb light in the portions of the spectrum to which our atmosphere is transparent, because these molecules possess no dipole moment. Thus, a direct spectrographic verification of the above argument appears to be impossible. However, H_2 under high pressure and low temperature does exhibit a weak quadrupole spectrum in the photographic infrared. Herzberg (*2*) has observed these absorptions in the laboratory and has shown that a feature observed in the spectrum of Uranus and Neptune by Kuiper at 8270 angstroms is probably due to this absorption of H_2. Since Herzberg found this line in the laboratory at 8258 angstroms, there is a small discrepancy which requires explanation.

The quadrupole spectrum of H_2 is not observed on Jupiter because the amount of gas above the clouds is too small and the temperature is too high to permit a sufficiently sharp line to be developed. Nevertheless, if Uranus and Neptune could retain hydrogen, the more massive Jupiter certainly could do so.

Temperatures on Jupiter

The radiometric technique for determining planetary temperatures indicates about −145°C for Jupiter. However, this is too low, because NH_3 plays the same role on Jupiter that CO_2 does on Venus. That is, the infrared energy measured by the radiometer comes partly from cold ammonia gas high in the atmosphere and partly from the warmer cloud surface below. Methane does not interfere with infrared radiation, since such symmetrical molecules have no infrared spectrum. The temperature is probably sufficiently low, even at the cloud surface, to cause condensation of ammonia into the solid form. It is very likely that the clouds are predominantly NH_3 crystals—that is, "ammonia cirrus." Indeed, this assumption offers the most delicate way of estimating the temperature of the clouds. Since we know the total amount of ammonia in a vertical column, we can estimate the ammonia vapor pressure at the visible surface. But when condensation occurs, this vapor pressure is a known function of the temperature alone. The only assumption which must be made is that the ammonia is well-mixed vertically and not concentrated at the bottom of the vertical column. This assumption cannot disturb the results very much because, fortunately, a large change in NH_3 vapor pressure implies a small change in temperature at condensation. Nevertheless, this means that the cloud temperature of −120°C, calculated in this way, is a lower limit. The actual temperature may be a few degrees higher.

In contrast, methane cannot condense at so high a temperature at any conceivable pressure. Thus, in principle, it is possible to determine relative elevations of the visible cloud surface by measuring the intensity of absorption by methane at various points on the planet. Similar measurements for ammonia should give the temperature distribution over the planet. Such measurements and calculations (*18*) indicate that the cloud surface is lowest at the equator at local noon and is about 10 kilometers higher near latitudes 60°N and 60°S, and 10 kilometers higher at longitudes 60°E and 60°W of the central point along the equator. The temperature was found to be highest at the equator at local noon and about 6°C cooler at latitudes 60°N and 60°S. Along the equator the temperature was also found to decrease towards the east and west limbs. At 60° of longitude away from local noon, towards the evening limb, the temperature was 4°C cooler than at local noon. The corresponding point on the equator towards the morning limb was 8° to 9°C cooler than at local noon. This is

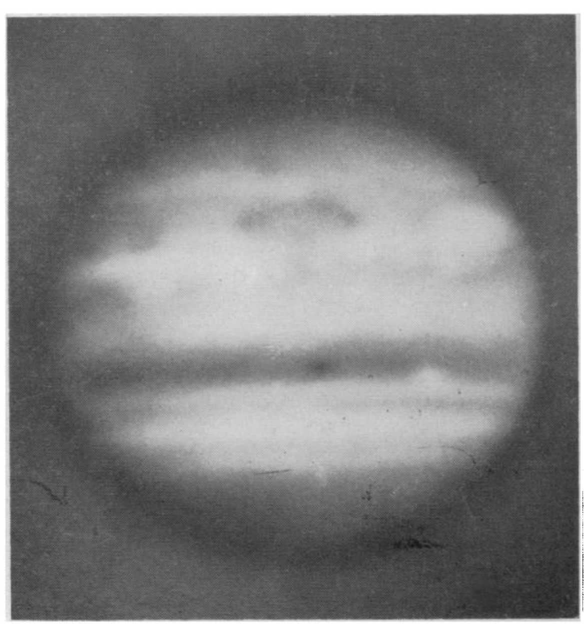

Fig. 3. Blue-light photograph of Jupiter in 1928 showing the banded structure, a variety of cloud features, and the Great Red Spot in the upper central part of the disc. The dark cloud feature to the left of the Great Red Spot moved relative to the dark clouds just below the spot with a speed of 8000 miles per day. [Photograph by E. C. Slipher, Lowell Observatory]

the kind of asymmetry in the diurnal temperature curve which one would expect if solar heating plays a major role in the planetary heat budget. There is considerable variation of opinion about the importance of heat that emerges from a possibly warm interior, but these ammonia-temperature data suggest that solar heating is dominant.

Cloud Motions on Jupiter

Because of the profusion of persistent cloud features, it is possible to gather extensive data concerning cloud motion. These data have been gathered and published for many years by the Jupiter section of the British Astronomical Association. Despite the large amount of information available, we do not understand the Jovian general circulation at all well because the atmosphere is so complex. The contrast to Mars is quite frustrating, for there the atmosphere is simple enough so that we could probably explain the circulation reasonably well if we had an adequate description. However, Martian cloud-drift data are so rare that we have difficulty in describing the features to be explained.

The outstanding circulation features of Jupiter are these: (i) The flow is primarily zonal, with rare northward and southward motions, and (ii) the equatorial zone (about 8°N to 8°S) rotates with a period of approximately 9 hours and 50 minutes, while the rest of the atmosphere rotates with a mean period of 9 hours and 55 minutes. This difference corresponds to a difference in zonal speed of about 200 miles per hour. A similar more rapid rotation near the equator is also observed on the sun and on Saturn. It may be a characteristic of very deep atmospheres. Although attempts have been made to explain theoretically such so-called "equatorial accelerations," these explanations fall short of being convincing. We have virtually no understanding of this phenomenon.

Poleward of latitudes 8°N and 8°S there are relatively small fluctuations in rotation rate which are associated with the alternation of light and dark bands. The wind shears observed indicate that the light bands are anticyclonic high-pressure belts with upward motion and that the dark bands are cyclonic low-pressure belts with descending motion (*19*). The ascent produces adiabatic cooling and increased condensation of ammonia; this explains the high reflectivity of the light bands. The descent produces adiabatic warming with evaporation of the ammonia clouds; this explains the low reflectivity of the dark bands.

Jupiter's "Great Red Spot"

An outstanding puzzle is the "Great Red Spot," a visible oval about 25,000 miles long and 8000 miles wide found near latitude 22°S. This object has been present for at least the last 80 years and probably for more than 100 years. It is characteristically brick-red, although it is sometimes white. The shape and dimensions fluctuate somewhat but give the impression of frequently returning to a fixed basic state. These facts strongly suggest that the Great Red Spot is a solid mountain-like mass protruding through the cloud layer. The changes in shape and size then would be due to small variations in the level of the clouds, and the change from red to white can be thought of as arising from deposition of ammonia snow on the mountain. Indeed, the manner in which cloud matter flows around the Great Red Spot strongly resembles the flow of the terrestrial atmosphere around the Tibetan plateau, which is in shape and relative size an analog of the Great Red Spot. A difficulty arises from the fact that this object does not rotate with a constant period. Therefore, it cannot be fixed to the solid part of the planet below the clouds. It has been suggested that it is a floating island with its base well below the cloud surface. This would, indeed, explain all the observations, but it is very difficult to imagine what solid substance can have a sufficiently low density to float in an atmosphere. The metallic phase of solid hydrogen has been suggested, but it is unlikely that this substance could persist at the low pressures in and near the visible cloud surface. The problem remains unsolved.

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