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*ON THE PHYSICAL CONSTITUTION OF THE PLANET JUPITER.**

THE planet of Jupiter was one of the first objects to which the telescope of Galileo was directed, and the satellites of the planet were among the earliest discoveries made by that instrument. In 1630 the telescope had been constructed with sufficient power to show the great equatorial belt. Previous to the beginning of the eighteenth century the principal phenomena seen on the surface of Jupiter had been observed, and the time of rotation and position of the axis of the planet ascertained. Notwithstanding, however, the great mass of facts which have been collected from observations extending over a period of 200 years, yet up to the present time no theory of the physical condition of the surface has been advanced which has met with universal acceptance. In order that the subject may be more clearly understood it will be well to state briefly the salient features presented to the eye of the observer. The disk of Jupiter appears as an ellipse having axes in the ratio of 14 to 15, the longer axis lying in the direction of the planet's equator. The equatorial diameter is about 89,000 miles.

* Address of the chairman of Section A, Mathematics and Astronomy, and vice-president of the American Association for the Advancement of Science. Read at the Washington meeting, December 29, 1902.

Now as the axis of the planet is nearly perpendicular to the line of sight, we shall see objects in their true dimensions only near the middle of the disk and on the equator. In the revolution of the planet in its orbit, the equator, as seen from the earth, may be displaced 3.3 degrees. Therefore, all objects seen on the disk may apparently be shifted in latitude. At the equator the displacement may amount to 1.1″ of arc, or about one sixteenth of the polar diameter, while in higher latitudes it will be very much less, and at the latitude of 70 degrees the displacement will be only 0.28″ of arc.

During the past twenty-five years some astronomers, who have observed Jupiter for years, imagine that when the planet is turned with its axis three degrees toward the earth, one would be able to see to the pole and beyond. I may say that this is a mistake, for the reason that the displacement of three degrees would amount to only 0.03″ near the pole. It is very rare that any objects are seen beyond 40 degrees of Jovian latitude. The latitude of 70 degrees is only 1″ from the limb, and 80 degrees only 0.25″ from the limb of the planet. Hence objects, if they existed at high latitudes, would be practically invisible. During twenty-three years of observation I have never observed a separate marking beyond 42 degrees of Jovicentric latitude, or 5.7″ of arc from the limb, except on one night when a small white spot was seen in latitude 62 degrees, or within 2″ of the south limb of the planet. Usually a fine shading or discoloration of the disk is seen near the poles. The planet rotates on its axis in a little less than ten hours, and hence the shape and size of an object in passing across the disk will be materially modified by the effect of rotation. An object, when it is first brought into view on the disk by rotation, is infinitely short in length and, as it is brought farther on by rotation, the length is increased, and reaches its maximum when on the central meridian of the disk. In passing off, it of course goes through the same changes in apparent size. As the meridians on a globe are curved lines, objects in passing across the disk may apparently be displaced in longitude in regard to each other, due to the curvature of the meridian, viz., two spots lying in different latitudes might at one time be on a line parallel to the polar axis of the planet and, when brought on the middle of the disk, would lie in different longitudes. Some astronomers have been misled by phenomena of this kind, considering it to be a real motion of the object, when in fact it is simply displacement due to rotation.

In order then to know what phenomena are real and what are apparent, it is necessary to take into account the position of the earth with regard to Jupiter's equator, as well as the position of the object on the disk of the planet.

Jupiter is distant 5.2 times the distance of the earth from the sun, and at mean distance 1″ of arc amounts to 2,300 miles. Now owing to the great distance of the planet from the earth, the objects we see must have considerable size in order to be visible. I presume that the smallest object which has been observed for longitude or latitude is at least 2,000 miles in diameter. In the case of a line or streak one might be able to see with the aid of the modern telescope 0.1″ of arc in width, which on Jupiter would be 230 miles, but all the markings which have been observed are considerably greater in size than this minimum value. The ordinary spots we see on Jupiter, from which rotation time has been determined, have usually been upward of 3,000 miles in diameter, where the spot is circular or elliptical.

I began systematic observations on Jupiter in the year 1879, and these have been continued every year with the exception of the opposition of 1888 and a part of

1889, when the telescope was dismounted. I may say that, previous to this period, the observations of phenomena have usually been made by estimation. This was true with regard to the determination of longitude almost without exception, and very few positions in latitude have ever been determined with the micrometer. Amateur observers, who have no driving clock or micrometer, must necessarily rely on eye estimates for longitude and latitude, but when a telescope is equipped for micrometer work there is no better excuse for guessing than in the determination of the distance of a pair of double stars.

Sketches or drawings of the planet Jupiter are of very little value in the absence of other data. It is not unusual to find the latitude of conspicuous markings eight or ten degrees in error, and longitude a corresponding amount. At the beginning of my observations on Jupiter I decided to fix the size and position of all objects seen on the disk by micrometrical measurement. By such a system of procedure positive facts will be established, which in time may enable us correctly to interpret the complicated phenomena observed.

During the past twenty-five years the so-called canals and double canals on Mars have been the subject of much discussion. I believe if their position were fixed by micrometrical measurements, we should soon be able to decide what is real and what is imaginary.

In order to use the micrometer for measurements on a planet, it is necessary to know the size of the disk. Jupiter has been measured by many astronomers, both with the micrometer and with the heliometer, but the measurements made differ considerably, due to two causes. First, irradiation, which depends on the size of the telescope, or rather on the magnifying power employed. Second, the increased size of the image, due to the condition of the atmosphere. In the use of the heliometer the true irradiation may be eliminated, but not the increased size of the disk due to definition. In any case the measured size of the disk depends directly on the magnifying power employed.

In 1880 I made a series of measures of the polar and equatorial diameter of the planet with powers of 390 and 638, and in 1897 a series of measurements with powers of 390 and 925. In all cases, whatever the condition of the seeing, the lower power gave the larger diameter. From the measures made on six nights in 1897, when the seeing was good enough to be able to use a power of 925, the difference for the two powers employed was: polar, $+0.27''$; equatorial, $+0.31''$. In 1880 for ordinary seeing the difference for the two powers employed amounted to $1''$. In order, therefore, to have some standard of size it would be necessary to decide upon the magnifying power employed with which the measures were made. Because of this apparent change in the size of the disk due to definition, to locate with precision any object on the surface of the disk, or a satellite off the disk, it is necessary to refer the object to both limbs of the planet at the time of observation. If the object is referred to only one limb, under unfavorable atmospheric conditions an error of $1''$ of arc would be easily possible, but if it is referred to both limbs, then the effect of the irradiation, or enlargement of the disk, is almost wholly eliminated. In the reduction of my micrometrical work on Jupiter I have used the values $18.33''$ and $19.48''$ for the semi-axes of the planet at mean distance.

These values for the size of the disk were found from a great many differential measures made in 1880–1 with a power of 390, and are somewhat larger than those given by the heliometer, owing to irradiation, but they will probably better satisfy micrometer work.

The observations for longitude, latitude and magnitude of objects on the planet Jupiter have all been made with the parallel-wire micrometer, preferably near the central meridian, but no rigid rule is followed in this respect. The longitude and latitude are usually determined whenever the spot or marking is wholly on the disk and distinctly visible.

The longitudes are measured by ascertaining the distance of the apparent center of the object from the limb of the planet, according to the method I pointed out some years ago. A determination of longitude or latitude generally consists of three bisections of the object and each limb of the planet. In the case of longitude, one half of the difference of the distances at the mean of the times is the distance of the apparent center of the object from the central meridian on the visible disk. This method of determining longitudes has been found to be greatly superior, in point of accuracy, to the method of transits, as well as a great saving of time.

The error in measurement of objects on a luminous disk is about twice as great as that from the measurement of double stars of equal distance. The ordinary error for location of objects in latitude or longitude on the disk of Jupiter may be placed at about 0.25″ arc.

Twenty-five years ago it was almost the general opinion among astronomers that the phenomena seen on the planet Jupiter were transitory in their nature; that there was no permanency in the spots and markings, but that the aspect of the planet changed from day to day, and even at less intervals of time. Perhaps we shall get a better idea of what was known about the subject by quoting from Grant's 'History of Physical Astronomy':

"Although generally there appear only three belts upon the disk of the planet, sometimes a greater variety is perceptible. Sometimes only one belt is visible. This is always the principal belt situated on the northern side of the planet's equator. On the other hand, its whole surface has occasionally been seen covered with belts. On the 18th of January, 1790, Sir William Herschel, having observed the planet with his forty-foot reflector, perceived two very dark belts dividing an equatorial zone of a yellowish color, and on each side of them were dark and bright bands alternating and continuous almost to the poles. A similar appearance was once noticed by Messier. These phenomena sometimes undergo very rapid transformations, affording thereby a strong proof that they owe their origin to the fluctuating movements of an elastic fluid enveloping the body of the planet. On the 13th of December, 1690, Cassini perceived five belts on the planet, two in the northern hemisphere and three in the southern hemisphere. An hour afterwards there appeared only two belts nearer the center and a feeble trace of the northern belt. The same astronomer frequently witnessed the formation of new belts on the planet in the course of one or two hours. The dark spots on the disk of the planet also afforded unequivocal indications of the existence of an atmosphere, for it is impossible to reconcile their variable velocity with the supposition of their being permanent spots adhering to the surface of the planet. Cassini found from his observations that the spots near the equator of the planet revolved with greater velocity than those more distant from it. Sir William Herschel found that the velocity sometimes underwent a sensible change in the course of a few days. He supposed the spots to be large congeries of cloud suspended in the atmosphere of the planet, and he ascribes their movements to the prevalence of winds on its surface which blow periodically in the same direction.''

Lardner, in his 'Astronomy,' says: 'In a month or two the whole aspect of the disk may be changed.'

In my annual report to the Chicago Astronomical Society for the year 1881, I stated that the phenomenon seen on the surface of Jupiter was of a more permanent character than had hitherto been believed to be the case.

In 1878 a large and conspicuous object known as the Great Red Spot was seen on the disk of Jupiter. It appears that this object was first noted on June 2, by Lohse, of Potsdam, but in looking up previous records, we find a spot seen in the same locality by the ancient astronomers. In the years 1664–6, a great red spot was observed by Hook and Cassini. It was situated one third of the semi-diameter of the planet south of the equator in latitude 6″. Its diameter was about one tenth the diameter of Jupiter, or about 8,000 miles. This spot appeared and vanished eight times between the years 1665 and 1708. From 1708 to 1713 it was invisible; the longest time of its continuing to be visible was three years, and the longest period of its disappearing was five years. Since its appearance in 1878 it has been visible with large telescopes during the whole period, but at times so faint that, except for the indentation in the equatorial belt, the spot, perhaps, would have been lost to astronomers, as it was formerly when they had smaller instruments.

The great red spot is 11.61″ or 37.2 degrees in length, and 3.87″ in breadth, or about 27,000 miles long, 9,000 miles broad, elliptical in outline, and, if we suppose the depth of the spot equal to its width, its volume would be about three times that of the earth. This object, which seems to have great permanency, is not stationary in either longitude or latitude.

It was visible in 1869 and 1870, when it was observed by Gledhill on four nights from November 14 to January 25, and on one night by Mayer. The data for ascertaining the rotation period have been derived from the drawings made, and necessarily are approximate.

The rotation period was $9^h\ 55^m\ 25.8^s$, or about eight seconds less than it was in 1879. From the observations made in 1878 I derived a rotation period of $9^h\ 55^m\ 33.7^s$. Since the rotation period had been increasing for twenty years, the observations in 1869 are of value in tracing the motions of this object.

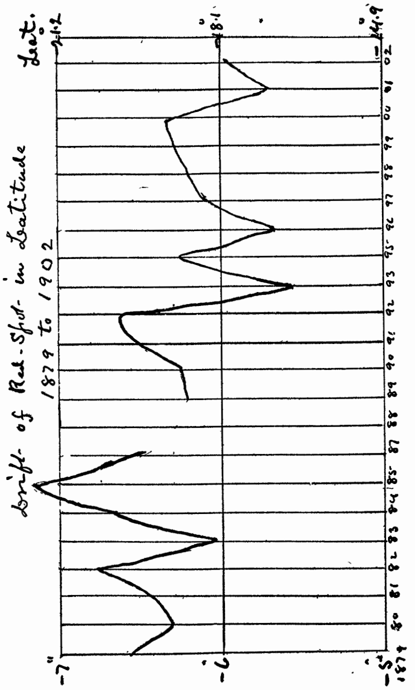
I may add that Mr. W. F. Denning, who has compiled the observations of what is presumed to be the red spots from 1831 to 1899, finds a rotation period of $9^h\ 55^m\ 34^s$ between 1869 and 1878, by assuming the number of rotations between consecutive observations. But where the interval is five years and upwards this is a very unsafe method of procedure, as will be perceived from the motions which have been studied during the last twenty-three years.

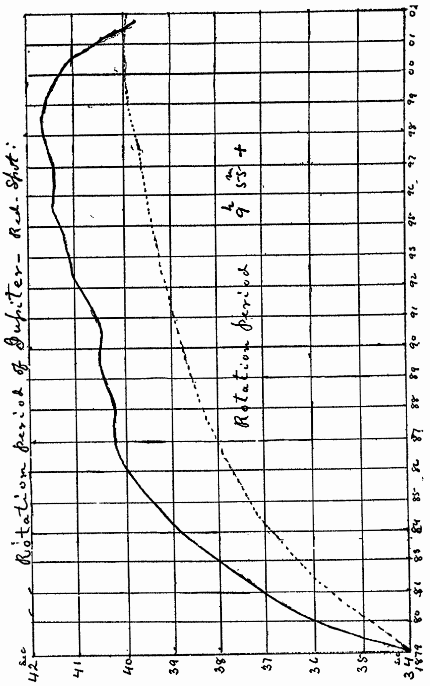
From the measures which I have made every year I have determined the rotation period for the red spot from 1879 up to the present time, and with the minimum value in 1879 of $9^h\ 55^m\ 34^s$. The diagram shows the rotation period at any point between 1879 and the present time. The vertical lines are intervals of 400 days, one day more than the synodic period of the planet. The horizontal lines represent seconds of arc, so that the rotation period at any point will be shown on the curve, the seconds being at the left hand of the diagram, and the time at the bottom of the diagram. The rotations for this curve were computed for intervals of 400 days by using at each epoch about twelve normal places, and the probable error on the rotation period, as determined in this way, varies between ± 0.02 sec. and ± 0.07 sec. The curve is perfectly smooth for the first six years, showing that the motion of the spot was very regular. Since that period the curve is not absolutely smooth, which may be due to the faintness of the object, and the shifting of the center from which the measurements were made, when the measures were referred to the bay in the equatorial belt. My measures, when the spot was very indistinct, have been referred to the center of the bay, and that may account for the small irregularities in the curve during the later years. From the diagram it is seen that the rotation period of the planet reached its maximum between 1898 and 1899, being 41.7 seconds. Previous to 1898 the spot had an apparent retrograde motion on the disk of the planet, and since that time the spot apparently has come to rest, and now has a direct drift around the planet. The rotation period for the last 400-day interval is 39.75 seconds, but the actual period at the present time is about three seconds less than it was in 1898. From the inspection of this curve, taken in connection with the rotation period which I found for 1870, it would seem to require a long cycle to make the rotation period the same as it was in 1879. The dotted curve indicates the 'mean' rotation period at any instant, counting from September 25, 1879. The 'mean' period for the interval 1879 to 1902 is $9^h\,55^m\,39.93^s$.

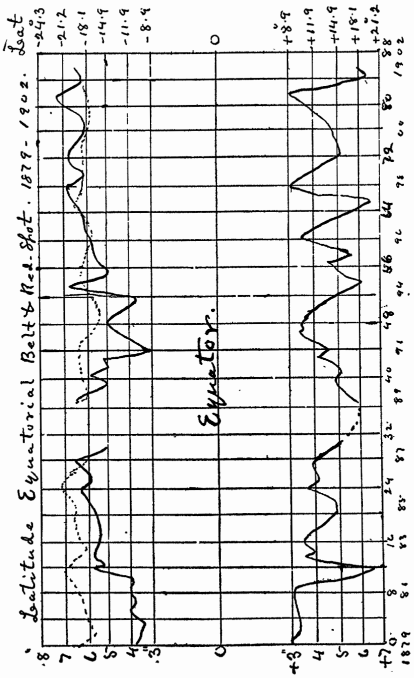
In 1880, when the red spot was most conspicuous, it was seen, when brought on the disk by rotation, at 87 degrees of longitude, or $2^h\,35^m$ in time from the central meridian, when its length was only second of arc. When the spot is wholly on the disk its longitude is 71.4 degrees and the apparent length 3.7″. It is possible that the rotation period may be connected with its visibility, viz., when the spot comes back to the same rotation period it had in 1879 it may become more conspicuous and reddish in color. This object has drifted in longitude about three and one fourth times around the planet since 1879, assuming the rotation period at that time to be the true rotation period of the planet. It seems to me, however, more probable that the time of rotation of the planet is longer than any period hitherto determined, in which case all objects would drift in the same direction. The object also has a motion in latitude, and the total displacement in twenty-three years has been 1.7″, or about 4,000 miles drift in latitude. The rate of drift in longitude and the visibility may possibly be due to the greater or less submergence of the spot in the material which composes the surface of the planet.

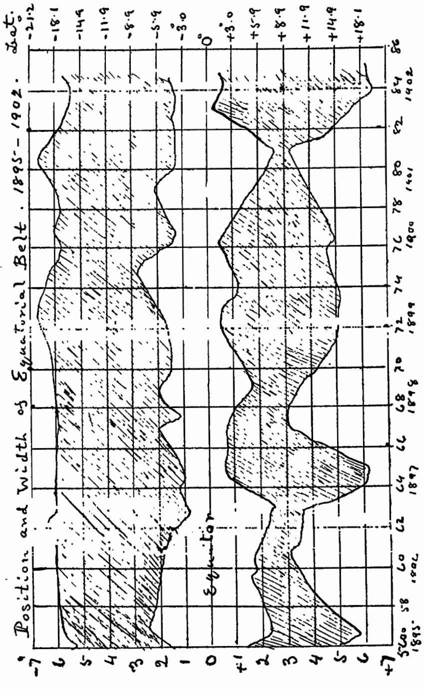
The diagram shows the mean latitude of the red spot at each opposition corrected for the elevation of the earth above Jupiter's equator. It seems that during these twenty-three years the spot has approached nearly 1″ nearer the equator than it was in 1879. The short time scale, the vertical lines being intervals of 400 days, makes the displacement appear more abrupt than it really is. The Jovicentric latitude is given on the right hand of the diagram. At the present time this is about eighteen degrees. We might add that this displacement in latitude of the red spot is very much less than the displacement of the great equatorial belt.

The most conspicuous marking on the surface of the planet is the great equatorial belt, which is always visible. This belt may appear as one belt, but usually is composed of two portions lying on either side of the equator of the planet. In 1880 it was practically one belt extending without break for a short time across the surface of the equator. From the study of the


Drift of Red-Spot in Latitude
1879 to 1902


Rotation Period of Jupiter-Red-Spot.
Rotation Period 9h 55m +


Latitude Equatorial Belt & Red-Spot. 1879-1902.
Equator.


Position and Width of Equatorial Belt. 1895-1902.
Equator

changes in this belt one may arrive at some idea regarding motions taking place on the surface of the planet. The systematic determination of motion in latitude has never been undertaken by any one previous to the observations which I began in 1879. Occasionally latitudes have been measured during one opposition. Arago, in 'Astronomé Populaire,' raised the question whether the belts on Jupiter are fixed in size and position, and he gives some measures of the positions from 1811 to 1837, and takes the mean of these various measures for getting the mean position of the belts on the planet. These observations are approximate, and are used without regard to the position of the earth above and below Jupiter's equator. From 1879 to the present time the latitude and width of the great equatorial belt have been measured on nearly every observing night, so that we may ascertain the position of the edge of the belt at any instant. It is found that the north edge of the belt has had a drift in latitude of nearly 4″ of arc or 12 degrees, and the south edge about the same amount. The changes in the drift of the belt are usually slow and gradual, but it is possible sometimes that considerable change may be observed in the course of a few days. The diagram indicates the position of the edge of the belt from 1879 to 1902, and it is of very great interest in showing at a glance the changes that have taken place in latitude. From the study of this diagram it appears that the disturbances take place on both edges of the belt at practically the same time. The matter composing the belts generally has a motion on both sides of the equator in opposite directions.

In 1879 the whole width of the belt was about 7″ of arc. In 1882 it widened out and has at times reached a width of about 13″ of arc. The edges of the belt remain practically parallel to the equator in all longitudes. I have noticed two marked exceptions. On October 3, 1882, there was a curved projection in longitude plus 30 minutes, following the great red spot. On October 14 the edge was smooth at the same longitude and the whole belt had drifted so far north as to coalesce with B_3. Also on February 24, 1897, in longitude plus five hours, the preceding half of the north edge of the belt drifted about two seconds farther north than the following portion. On February 27, however, the edge of the belt was comparatively smooth in the same longitude.

Aside from the drift of the edges of the belt in latitude, the belt itself changes dimensions from time to time to a considerable extent, and these changes have been studied from micrometrical measurements since 1895. The diagram shows the width of the two portions of the equatorial belt at any instant from 1895 to 1902. The diagram indicates the width and not the shape of the belt at any time. Now it is seen, taking the portion of the belt north of the equator, at times it becomes very narrow; for instance in 1896 it was about 1″ arc in width, 1897 it was about 5″ in width, and then it became narrower again in 1898, and continued wide from that time until 1901, when it was less than 1″ arc in width and appeared as a faint line on the planet. The south portion of the belt has not passed through so great change during the five years, and has been more steady in latitude and width. On either side of the equator are fainter belts which usually extend to 40 degrees of latitude as separate belts. These faint belts are subject to change, in both size and position, from year to year.

On the belts and on the surface of the planet there are frequently seen small spots, sometimes white and sometimes black, viz., 2,000 miles or more in diameter, and from the observations of these spots we have determined the rotation period of the planet for different parts of the surface. The spots, which appear near the north margin of the equatorial belt nearly every opposition and are sometimes permanent for two or three years, and have a slight motion in latitude, only a fraction of 1″ of arc, whereas the belt may move 3″ or more in latitude in one year. It seems to me that this fact has an important bearing as to location of the objects, viz., the belt and the spots. I infer from the slight displacement of the spots that they lie at a lower level in the Jovian surface than the equatorial belt, and for the same reason the great red spot lies at a lower level.

The transits of the satellites of Jupiter offer phenomena which have a direct bearing on the constitution of the planet. The satellites at times cross all parts of the disk in transit. For a normal transit the satellite disappears at some distance from the disk after ingress and reappears at a similar distance before egress. From this fact it is concluded that the center of the disk of Jupiter has the same reflecting power as the satellites. With the $18\frac{1}{2}''$ refractor I have ascertained that a satellite can be followed for a distance of 10″ of arc from the limb or nearly one quarter the diameter of the disk before it disappears in transit. However, when the transit occurs within 10″ of the north or south limbs, the satellite can be seen during the entire transit across the disk. Now since the satellite is not supposed to be hot enough to give light, we conclude there is not sufficient heat in the planet to produce light. The observation of the eclipse of the satellite also shows that it has no inherent light of its own.

Aside from the period of $9^h\ 55^m$, some spots and markings give a shorter period of $9^h\ 50^m$, indicating that these objects have a motion of about 250 miles an hour in the direction of the planet's rotation, assuming that the true rotation period is $9^h\ 55^m$. For mechanical reasons the spots which give this shorter period must necessarily be located above the spots which give the longer period of $9^h\ 55^m$. From 1879 to 1885 two white spots in latitude 6 degrees south were observed every year, giving a rotation period of $9^h\ 50^m$ plus. The white spots, during the last twenty years, which give this short period, have been observed between the latitudes plus 11 and minus 8, and also in one year, in 1891, black spots which gave a short period were observed in latitude 20 degrees north. The spots and markings which give the long period of $9^h\ 55^m$ have been observed in latitudes between 37 degrees north and 38 degrees south and within 12 degrees of the equator.

The equatorial belt sometimes approaches the equator very closely, and its rotation for some years has been the same as that of the great red spot, for the spot and the belt have, as we know, maintained the same position toward each other. Hence we find the longer rotation period of $9^h\ 55^m$ in precisely the same latitude as the shorter period. On examining the table of rotations there does not seem to be any connection between latitude and rotation period, as has often been alleged. The longest period which I observed, covering an interval of 156 days, is $9^h\ 56^m\ 0.4^s$, which was in latitude 26 degrees north.

Mr. A. S. Williams has written some articles on the rotation of the surface of Jupiter in which he finds zones of constant currents. These speculations are not sound, for the reason that in the same latitude we find different rotation periods for the same instant of time, and, as I have said before, there is no law connecting rotation period with the latitude, except we find this period of 9^h 50^m more commonly between the limits of -8 and $+11$ degrees, whereas the longer period is distributed indiscriminately over the surface of the whole planet as far as 38 degrees latitude.

The question has sometimes been raised as to whether the phenomena on Jupiter were periodic. The inclination of Jupiter's equator to its orbit being only three degrees, any periodicity due to the revolution of Jupiter around the sun should recur at intervals of about twelve years, but from the motions which I have shown for the displacement of the belts in latitude there does not seem to be any regularity in the period. I presume any periodicity is of the same nature as we have in the meteorology of the earth. We have, of course, a sequence in the seasons and a sequence in weather conditions, but our sequence in weather conditions does not follow any regularity, and if changes on Jupiter are due to meteorological causes, we should not expect to find any definite period.

The application of photography to astronomical observations has been of great value in various directions, but up to the present time it has been of no benefit in the study of planetary details. Photographs of the planet Jupiter have been made since 1880 at different times, but they only show the simple outline and some of the conspicuous markings. The scale of photograph is so small that it cannot be used with any degree of success for determining position on the disk. There is no question, however, that if we are ever able, by increasing the sensitiveness of our plate, to make an enlarged photograph of Jupiter or Mars such as is seen through the telescope with the eye, it would be a great advance, and it would enable us to decide very many questions, which are now impossible owing to the limited time that we are able to study the object under consideration, due to the rapid motion of the planet on its axis. The phenomena seen on the planet depend in a great measure on the size of the telescope and the magnifying power employed. In my work on Jupiter I have habitually used a power of 390, which is adapted to most conditions for seeing and will show minute detail. With the same telescope, using a power of 190, the appearance of the disk is quite different, and minute detail cannot be seen with distinctness. The observers who have small telescopes of five or six inches in aperture and use a comparatively low power do not see the phenomena as they would be shown by larger telescopes and high power. Hence in any question of disagreement, observation with the small telescope should have very little weight. The principle is precisely the same as in the observation of double stars. While a pair of close or unequal double stars may be easy objects for $18\frac{1}{2}''$ object glass, they are entirely beyond the range of a $6''$ object glass.

A misinterpretation of phenomena has given rise to very erroneous notions regarding the changes which take place on the surface of the planet. When we look at the planet Jupiter, we see only about one fifth of the surface in longitude distinctly at any one time, and hence in the course of two hours we should have an entirely new set of features under view of the eye of the observer. The faint belts north and south of the equator sometimes only extend over a portion of the circumference of the planet, and in such case one might see a greater or less number of belts after the interval of two hours or more, as has been stated by Cassini and others.

My observations during the past twenty-three years have established the following facts:

1. The equatorial belt changes in both size and position to a considerable extent, but these changes are usually slow and gradual. Occasionally, however, a marked change may be observed in the features of the belt in the course of a number of days.

2. The fainter belts also are displaced in latitude and in the amount of material of which they are composed. The visibility of the fainter markings and spots depends in a considerable measure on the distance of the planet from the earth. When the planet is at more than mean distance, the so-called polar belts are very faint and sometimes invisible, even with a large telescope, and are not brought into view until the planet approaches toward opposition. This fact I noticed particularly in the early years of my observation on Jupiter, when the observations were made as near the sun as possible.

3. The egg-shaped white spots, which appear in this form from perspective, as they are probably nearly circular, are found both north and south of the equator and are very permanent in latitude. They are usually from one to two seconds of arc in diameter. These spots are not fixed with regard to each other, even when they are located in the same latitude.

4. Aside from the white spots, there are dark spots of similar size, sometimes on the faint belts and sometimes entirely disconnected from the belt. The dark matter is not as stable as the egg-shaped white spots, and probably lies at the same level as the equatorial belt.

5. Near the equator are found white spots, usually of a larger size and more irregular in shape, which give rise to the period of $9^h\ 50^m$.

The mean density of the planet Jupiter is 1.37 times that of water. The spheroidal figure of the planet indicates that the density increases as we proceed from the surface to the center. In the case of the earth the density at the surface is about one third the mean density, and assuming the same rule for Jupiter, its surface density would be 0.4 to 0.5 that of water. The liquefaction of air and gases during recent years enables us to imagine a medium which would have the density corresponding to that of the surface of the planet. The older astronomers, of course, had no knowledge of any substance between atmosphere and liquid, and hence, in forming their theories of the motions on the surface of the planet, the theory was necessarily atmospheric, but there is now no excuse for maintaining an atmospheric theory which will not account for the phenomena observed.

A probable theory of the constitution of the planet should in some degree satisfy all the phenomena observed. No one can draw legitimate conclusions from casual observations. On the surface of Jupiter we find the following objects: (1) The great red spot, which is the most stable of all objects seen on the disk of the planet. During the period that its size has been measured with the micrometer one cannot say with certainty that there has been any change in its size or shape from 1879 to 1902. It is now conceded by astronomers that the object is identical with the spot observed by early astronomers. Such being the case, it would seem to be absurd to say that anything in the nature of a cloud should persist in the same form for more than 200 years. Its spheroidal shape in connection with its stability would seem to show that it has volume and mass. Its motion in latitude, as we have already seen, is much less than for the equatorial belt. The matter of which it is composed is in a different condition to that of the belt. In 1880 I had the good fortune to notice the transit of a satellite over the red spot. The satellite, which was invisible during transit, when projected on the spot appeared as bright as when off the disk. On the contrary, when satellites transit the belt they are invisible. (2) Egg-shaped white spots from 2,000 to 5,000 miles in diameter. These spots I have found in north latitude 13 to 37 degrees and in south latitude from 18 to 27 degrees. These objects do not look like clouds, and so far as we know they do not change their shape during the six months while under observation. They are also very stable in latitude and give a rotation period of $9^h\ 55^m +$. (3) Small black spots seen on the belts or entirely separate. These objects give a rotation period of $9^h\ 55^m +$, but on one occasion in latitude 20 degrees north I found a short period. (4) The dark matter forming the system of belts including the equatorial belt and the so-called polar belts, which also give a rotation period of $9^h\ 55^m$. (5) The white spots which give a rotation period of $9^h\ 50^m$.

It seems to be the opinion of most writers on Jovian phenomena that the planet is yet at a high temperature, but not self-luminous. The high temperature is favorable for the explanation of some of the phenomena observed. I have long held the opinion that a simple atmospheric theory was not sufficient. The greater luminosity of the center of the disk indicates absorption of light, probably due to an extensive atmosphere. The white spots which give a rotation period of $9^h\ 50^m$ are of different form and size from the egg-shaped spots which give the period of $9^h\ 55^m +$. The short period spots are greater in size and irregular in shape, sometimes appearing simply as a rift in the equatorial belt. Having these facts before us, we can formulate a theory which will fairly well satisfy all classes of phenomena.

I assume that the visible boundary of Jupiter has a density of about one half that of water. This medium is in the nature of a liquid; in it are located the great red spot and the egg-shaped white spots. In such a medium all motions in longitude and latitude would be slow and gradual, and the shape and size of the object would have great permanency. The equatorial belt and the so-called polar belts may be located on the surface or at a higher level than the red spot. In the middle latitude within twenty degrees of the equator the higher atmosphere carries a layer of dark matter in the direction of the rotation of the planet at a velocity of about 250 miles per hour, making a complete circuit around the planet in 44 days. In this envelope are formed the openings which we call white spots and, by unequal distribution, black spots. The great bay in the south edge of the equatorial belt may be accounted for by assuming that the great red spot is at a lower temperature than the medium in which it floats, and by its lower temperature condensing a portion of the vapor composing the belt. In 1882, when the edge of the belt drifted south, it did not come in contact with the spot at any point, although it advanced at times beyond the center. In 1883 I stated that the spot seemed to have a repelling influence on the belt. During the past twenty years, when the belt and the spot were in proximity a depression was formed in the belt directly opposite, which was of the same form as the contour of the spot. The belts may be assumed to be some sort of vapor of considerable density. The cloudlike matter, which in the equatorial regions is moving over the surface at the rate of 250 miles per hour would account for the minor changes on the surface of the equatorial belt. I think the theory I have given offers a more plausible explanation of the various phenomena observed than the off-hand statement that we see simply clouds floating in the atmosphere of the planet.

G. W. HOUGH.

THE ORIGIN OF TERRESTRIAL PLANTS.*

I SHOULD like to invite your attention for a little while to some of the factors that apparently have been operative in determining the changes which plant structures have undergone in the course of the development of the vegetable kingdom. While some of these are perfectly obvious, others are by no means so evident, and, as might be expected, there is not perfect agreement among botanists as to the relative importance of some of these factors, nor indeed of their efficiency at all.

I shall not attempt here to go into any extended discussion of the remarkable results obtained by Professor De Vries in his recent studies upon variation in plants. These are too important, however, to be dismissed without some mention. The conclusion reached by Professor De Vries is that, in addition to the variation within the limits of species, there may be sudden variations, or 'mutations,' which, so to speak, overstep the limits of the species, and thus inaugurate new species. While the results obtained, especially in the case of *Œnothera Lamarckiana,* are certainly most striking, more data are necessary before we can accept without reserve the conclusions reached. It is certain that marked changes—'sports,' as the gardeners term them—often appear without any explainable cause, and it is equally difficult to understand, what for want of a better term, we can only term 'tendencies' to develop in special directions. Thus the specialization of the sexual reproductive cells, which has evidently taken place quite independently in several unrelated lines; the development of heterospory, and probably of the seed-habit in different groups independently, are hard to explain without assuming an innate tendency to vary in a determined direction.

It is not, however, with these exceedingly difficult and often obscure problems that we shall concern ourselves here, but rather with those changes in plant structures which are referable to more or less evident response to known conditions.

Speaking in broad terms, I think we can reduce the determining factors to three categories, leaving aside the inherent tendencies to variation. These three sets of factors are: (1) those relating to the food supply, (2) the relation to water and (3) those concerned with reproduction.

It is hardly necessary to say that there is no fundamental distinction between plants and animals. At the bottom of the scale of organic life are many forms, especially those belonging to the group of Flagellata, which are intermediate between the strictly animal and vegetable organisms.

We may safely assume that the primitive organisms were motile, perhaps resembling some of the existing flagellates. Of the latter some are destitute of pigment and approach the lower Protozoa; others are provided with chromatophores containing chlorophyll and resemble the lower plants. It is highly probable that the forms with chromatophores are able to assimilate carbon dioxide, as the typical plants do, and may be denominated 'holophytic.' The forms without chlorophyll are probably, like animals, dependent upon organic food for their existence.

If we compare the holophytic flagellates with those forms which have no chlorophyll, a significant difference may be noted, which is evidently associated with

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