surface so as to be propagated downwards as a wave of heat is, on the average, much less than would be in a clear atmosphere similar to that in which Langley worked. Consequently the overplus of energy supplied in the warmer months of the year is probably overestimated. Then, again, there is some doubt as to the surface values of temperature as deduced from the Calton Hill thermometers, for a complete account of which I refer to a paper shortly to be published in the Transactions of the Royal Society of Edinburgh by Mr. Heath. Had I been sooner aware of the fact that Mr. Heath was preparing an elaborate discussion of the Calton Hill rock thermometers I should not have taken the trouble to make an harmonic analysis of the eight years' observations already published by Piazzi Smyth. These I have used as they were given, without any regard to the probable corrections. As my object was, however, to get an approximate estimate of the amount of heat stored in the rock at different times, and not to discuss the conductivity of the material, it was not necessary to pay much attention to comparatively small errors of observation. The probable heterogeneity of the different layers and the surface irregularities of the rock itself will give rise to disturbances as important as any that might arise from neglect of slight and, as Mr. Heath has pointed out, not very certain corrections.

It would be of great interest to apply similar calculations to underground temperatures in other parts of the globe, especially in parts which are blessed with fairly steady sunshine.

TABLE 9.—*Showing the time in hours, reckoned from culmination, at which for given values of the sun's declination, as shown in the top row, the radiation crossing unit horizontal surface, at the equator, has value as shown in the first column.*

R.	Sun's declination.			
	23° 27′.	20°.	12°.	0°.
0.700	....	......	......	0.00
0.679	....	......	0.00	......
0.643	....	0.00	......	......
0.622	0.00	......	......	......
0.606	0.77	1.12	1.55	1.68
0.512	1.98	2.11	2.34	2.46
0.421	2.69	......	......	......
0.331	3.27	3.35	3.48	3.54
0.249	3.79	......	......	......
0.091	4.73	4.76	4.81	4.83
0.060	4.94	......	......	......
0.007	5.47	5.49	5.51	5.52

TABLE 10.—*Total insolation at the equator.*

Declination.		Half-daily heating (relative).	Daily heating (absolute).
°	′		*Calories.*
+23	27	122.9	737.4
+20		127.4	764.4
+12		135.2	811.2
0		139.2	835.2
−12		135.2	811.2
−20		127.4	764.4
−23	27	122.9	737.4

[The numbers in the second column of Table 10 are shown in curve No. 7. They are calculated for the declinations in the first column, which latter correspond very nearly to the positions of the sun on the 20th or 21st of each month, from June to December, as we go down the column, and from December to June as we go up the column.]

In regard to the general form of the curves of underground temperature, there is one feature which I do not remember to have seen commented upon. The feature is apparent to all, but most evident in the curve for the thermometer nearest the surface. It is the sharpness of the crest as compared with the trough. The reason of this is at once recognized when we observe that exactly the same feature is distinctly characteristic of the lower solar radiation curve, but not so of the higher curve. In other words, in the higher latitude the low altitude of the sun and the shortness of the day combine during the winter months to produce a marked effect upon the law of absorption of solar energy. In lower latitudes this effect is hardly appreciable, and at the equator a perfectly symmetrical semiannual variation of comparatively small amplitude is to be expected. It is instructive to compare the annual variations of solar radiation already given for two different latitudes with the corresponding variations at a place on the equator. The results, obtained in exactly the same way [as for Tables 1, 2, 7, and 8], are given in Table 9.

Earth thermometers at the equator would, of course, show no annual period, and the semiannual period would penetrate to a comparatively small depth.

STUDIES ON THE CIRCULATION OF THE ATMOSPHERES OF THE SUN AND OF THE EARTH.

By Prof. FRANK H. BIGELOW, dated November 10, 1903.

I.—THE CIRCULATION OF THE SUN'S ATMOSPHERE.

HISTORICAL REVIEW.

That the solar atmosphere is circulating in accordance with the laws governing the convective and radiative action of a large mass of matter contracting by its own gravitation, is so evident that numerous efforts have been made to determine what these laws are, or at least to discover some reliable clue to a beginning of scientific research in that direction. The application by R. Emden[1] of H. von Helmholtz's method of adapting the general equations of motion to a solar mass, appeared to be a step in the right direction; further attention was called to the possibilities of this solution in my Report on Eclipse Meteorology,[2] pages 71–74. In June, 1902, Sir Norman Lockyer and Dr. W. J. S. Lockyer[3] published their suggestive curve of the percentage frequency of the solar prominences derived from the Italian observations for each 10° of solar latitude north and south of the equator. This curve interested me because it appeared to identify the distinctly solar phenomena with the short period curves which I had worked out in the terrestrial magnetic field and in the meteorological field of the United States, and first published in December, 1894,[4] afterwards republishing them in 1898.[5] A study of the difficult subject of inversion of periodic effects in magnetic and meteorological phenomena discovered at that time has been actively pursued by the Weather Bureau for the past ten years, and evidence is being accumulated, not only here but by others, of the existence and importance of the fact of inversion in the magnetic phenomena, the pressures, and the temperatures of the earth generally. The solar prominence curve suggested also the possibility of obtaining more decisive evidence of solar and terrestrial synchronisms than that afforded by the solar-spot frequency curve (which is apparently only a sluggish register of the true solar output of energy), because the terrestrial magnetic field and the meteorological elements show minor variations that are only feebly indicated in the solar-spot curve. The prominence frequency curves brought out distinctly for the sun the minor fluctuations that had been already found in the earth's atmosphere.

My first computations on the amplitudes of the deflecting forces which disturb the normal terrestrial magnetic field were computed for the years 1878–1893, using the records of several European magnetic stations. To have extended the same computation to the years 1841–1900, inclusive, would have re-

[1] Eine Beobachtung uber Luftwogen. R. Emden. Wied. Ann. LXII, p. 62, 1897, and Astrophysical Journal, January, 1902.

[2] Eclipse Meteorology and Allied Problems. Frank H. Bigelow. Weather Bureau Bulletin I. 1902.

[3] On some Phenomena which suggest a short Period of Solar and Meteorological Changes. By Sir Norman Lockyer, K. C. B., F. R. S., and William J. S. Lockyer, M. A., Ph. D., F. R. A. S. Received June 14. Read June 19, 1902. Addendum. Dated June 26. Proc. Roy. Soc. Vol. 70.

[4] Inversion of Temperatures in the 26.68 Day Solar Magnetic Period. Frank H. Bigelow. Am. Jour. Sci. Vol. XLVIII, December, 1894.

[5] Report on Solar and Terrestrial Magnetism in their Relations to Meteorology. Frank H. Bigelow. Weather Bureau Bulletin No. 21. 1898.

quired a vast amount of labor; as an equivalent, the deflections of the horizontal force alone, without the declination and vertical components, were derived by the construction of a series of graphical curves covering these sixty years, from which the mean ordinates were computed. The result was shown in my paper on Cosmical Meteorology, July, 1902.[6] The same variation curve was found from the horizontal force for the years 1878–1893 as that previously given by the computed σ curve, and it was therefore proper to conclude that this extension of the original computation in both directions was sufficiently correct for the purpose of the discussion. Furthermore, the prominence frequencies presented the material for studying the solar activity by zones, and the result of my compilation to determine the law of the movement of the points of prominence maxima in latitude was read before the American Association for the Advancement of Science on December 28, 1902, and published in the MONTHLY WEATHER REVIEW, January, 1903.[7] I there showed that in each hemisphere the maxima of prominence frequency are grouped in two zones, and that in the zones near the equator, in latitudes about 20°, the maxima of frequency approach that plane in common with the sun spots and faculæ during the 11-year period, while in the zones in latitudes 50°–70°, the maxima simultaneously move toward the poles. This indicates a characteristic tendency of the solar circulation to spread from the middle latitudes toward the equator and toward the poles in two independent branches. In a paper[8] published in March, 1903, the Lockyers obtained a similar result for the same phenomena. They gave the life history of the sun in the separate 11-year periods between 1872–1901, whereas my paper had grouped these three available periods together for the sake of finding the average law. Dr. A. Ricco[9] has published similar studies of the movements of prominences in latitude for the years 1880–1902. The subject of the average distribution of the solar spots in longitude on the sun has been discussed by Dr. A. Wolfer,[10] and from it he derived some determinations of the solar rotation in different latitudes. In my paper of January, 1903, I stated that besides a study of the variable distribution of the prominences in latitude, an effort was being made by me to discover some clue as to their distribution in longitude, in order to learn whether or not there was an accumulation on certain meridians, and it is the result of this work that is contained in the present paper. We have discovered an unexpectedly clear insight into the solar circulation, and this tends to strengthen the line of argument which I have been developing during the past fifteen years to explain the mysterious synchronism at the earth, of which numerous symptoms have been noted, in many kinds of observations.

COMPILATION OF THE PROMINENCE OBSERVATIONS.

The prominences which appear on the edge of the disk of the sun have been carefully delineated by the Italian observers Secchi and Tacchini with stations at Rome and Palermo, also Ricco and Mascari, at Catania, working in cooperation, from March, 1871, till the present time in an unbroken series. Students of solar physics can not too gratefully acknowledge the value of the patient, laborious work which has been done by these observers, and the practical study of these data is likely to open up new and important lines of research. Beginning with March 1, 1871, the images of the solar disk have been published in the Memorie della Società degli Spettroscopisti Italiani, and they cover the time to the end of the century, except for a long gap from September, 1877, to January, 1884. I am informed by Dr. Ricco that the drawings for these missing years are in the archives of the Catania Observatory, and it is obvious that steps should be taken as soon as practicable to complete the published record, because the demand for the data is sure to increase, as can be inferred from the results indicated in this paper. On those graphical tables certain lines were drawn showing the position of the north and south poles and the equator of the sun, so that the disk could be readily divided into zones, passing first along the eastern limb from north to south, and then along the western limb from south to north.

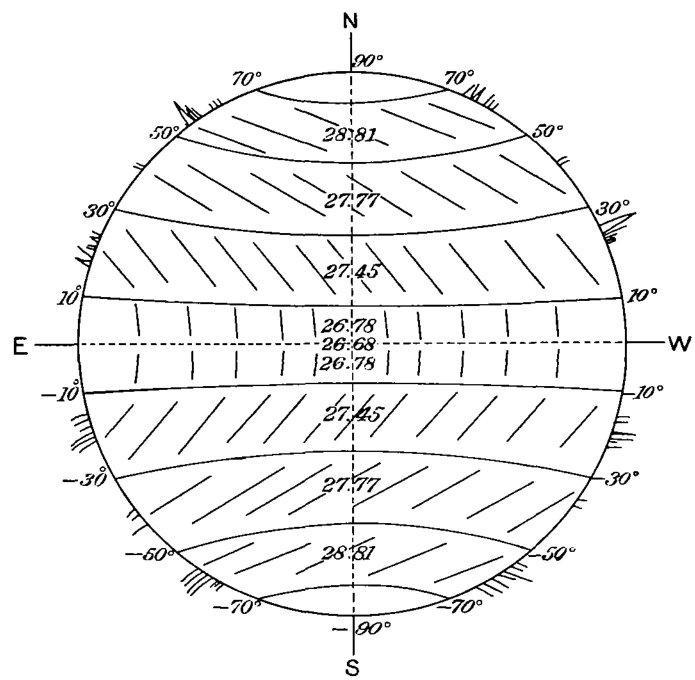

FIG. 1.—Retardation of rotation in different zones of the sun as derived from the prominence frequency in longitude.

The diagrams on fig. 1 serve to illustrate the general situation. Referring to fig. 4 of my former paper,[11] Synchronous Changes in the Solar and Terrestrial Atmospheres, it is noted that the prominence maximum activity is central in the zones 10° to 30° and 50° to 70° of each hemisphere, and on this account it was decided to subdivide the solar disk into 20-degree zones, as follows: + 90° to + 70°, + 70° to + 50°, ... — 50° to — 70°, and — 70° to — 90°, as indicated. A scale was prepared which when laid upon the published drawing of a given date would readily subdivide it into these zones on each side of the sun's limb.

For the sake of recording the relative energy of the solar output as registered in the prominences, a scale of estimation was adopted, as follows:

0 = an undisturbed limb for the zone.
1 = a minor disturbance.
2 = a somewhat extensive disturbance.
3 = a disturbance pronounced in altitude or along a considerable extent of the zone.
4 = a very large, emphatic agitation of the limb.
5 = the largest prominences, occurring but rarely.

The state of the limb was thus expressed in numbers of relative energy by estimation, care being exercised to make a similar relative number do duty whenever the style of the

[6] A Contribution to Cosmical Meteorology. Monthly Weather Review, July, 1902, Vol. XXX, p. 347.

[7] Synchronous Changes in the Solar and Terrestrial Atmosphere. Monthly Weather Review, January, 1903, Vol. XXXI, p. 9.

[8] Solar Prominence and Spot Circulation, 1872-1901. By Sir Norman Lockyer, K. C. B., F. R. S., and William J. S. Lockyer, Chief Assistant, Solar Physics Observatory, M. A. (Camb.), Ph. D. (Gott) F. R. A. S. Received March 17. Read March 26, 1903. Proc. Roy. Soc. Vol. 71.

[9] Le protuberanze solari nello'ultimo periodo undecennale. Mem. Spett. Ital., Vol. XXXII, 1903. A. Ricco.

[10] Publikationen der Sternwarte des Eidg. Polytech. Inst., Zurich. A. Wolfer. Bd. I, II, III, 1897, 1899, 1902.

[11] Monthly Weather Review, January, 1903, Vol. XXXI, p. 17.

TABLE 1.—*The prominence energy in zones as collected on the 26.68-day period, showing retardation in different latitudes.*

Period 26.679 days; Epoch June 13.72, 1887.

Zone +50° to +70°.

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
1891	Jan. 11	1		3	2												1	1												
	Feb. 6	2	1			1	2	2	2		4	2									2	4	4	2	3	2	2	2		
	Mch. 5	3		4	3		2			1															2					
	Apr. 1	4	2		2		4	3	2					1		1		1		2	2						1			
	Apr. 27	5						3	1										2		1									
	May 24	6	2		1				1	4	3	5	3	2	1				1			1		1						
	June 20	7	1			1				5	2	3	3	6	3		1	5	1	1	2	3								
	July 11	8	1							2	3	2	2	1	2	3	1	1	2	1	1	1	1	1			2		2	
	Aug. 12	9						1	1					2	4	8	5	4	5	4	5	4	4	3	1		1		1	
	Sep. 8	10			1	2	6	7	8	6	4	6	4	1	1	2	5	5	8	7	7	7	6	3	4	3	3	3		
	Oct. 4	11	4	2	3		4	3	4	3	1		3	4	4	8	3	6	3	4	6	7	8	3	3	7	4	2	1	
	Oct. 31	12		4						5		4	2		1	2	3	3	3	3	3	4	4			3		4		
	Nov. 27	13	2	1	2			2	2	4	4	4	3	4	3	1					2	2	2	1	2	2	2			
	Dec. 23	14			1	2					2	1				1	1				2	6			1					16
1892.	Jan. 19	1		1	2	1				1				2			2	1	5	3	1	1	1					1	1	
	Feb. 15	2			4			1	2			3		1				4			1	2			3			2		
	Mch. 12	3	3	3	3		2	1	2	3	2	3	4			2	2	2			1	1	1	2	2	1	2	4		
	Apr. 8	4	6	6	3	2		4	3	3			1	1	1	4	8	1	1		3	2	3		1	6	3	5	2	
	May 5	5	3	1	2	3	3		2	2	4	3	3	3	2				3	3	1	1		2			2	3		
	May 31	6	1	2		2	2	3	3	3	2	4	6	5	2	4	1		1	4	3	3	3	2	1	1	1	1	2	
	June 27	7	4	3	2	1		2	2	3	3	3	3	2	3	7			1		3	2	5	6	5	2	4	2	1	
	July 24	8	3	1	1				3	2	1	5	3	4	2	3	4	4	6	3	4	3		2	3	2	3	2		
	Aug. 19	9		3	3	1		1		1	2	2	4	1	5	5	5	3	4	4	4	4	4		2	2	2	3	1	
	Sep. 15	10	4			3		3	1		2		1	1	1	5	3	4	5	1	5	4	1	1	1			1		
	Oct. 12	11	3	3		1	1	5	4		2		2	1	2	1	2		3	5	2	3	2	5	1	2	2	6		
	Nov. 7	12	6	3		1	2							3	1		2		2	3	6	3	3	4	5		6	4	3	
	Dec. 4	13		3	3	3			4		2						2	2	2		2				2					17

Zone +10° to +30°.

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
1891	Jan 11	1			1	2									2	5	3	2	2				2				1	1		
	Feb. 6	2	2	5	2	1		1	1	1			1	1	2	2	1	2	1	1		2	1	1	1	4	3	1		
	Mch 5	3	2	3				1			1			2	1		6	6	2	6	3						2	2		
	Apr. 1	4	1		2	1	3	2	4	3				1	1	2	1	1	1	4	2	2						1		
	Apr. 27	5	1		1	1		3		1	3	2			1	3		1		1	3	1	3	1	1		1	3	1	
	May 24	6	1		1	2	2	1	1	4		1		1	5	8	2	1	2		3	4	4	3	4	1	4	5	2	
	June 20	7	3	3	3	2	1		1	3	4	3		7	3	7	3		1	2			3	2	3	2	3	3		
	July 11	8	3	5	1	2	1	3	2	6	4	4	2	1	3	4	5	5	1							2	4			
	Aug. 12	9	4	4	6	4	3	3	4	2	1	2	2	2	1	5	3	4			1	1			1		2	5	3	
	Sep 8	10	4	3	5	4	5	4	5	2	2	2	1	3			3	2		2		1				4	5			
	Oct. 4	11		2	4	1	3	1	2		2	1	2	1			1		1	3			1		1	1			1	
	Oct 31	12		2			1	2	3	2		3					4	1	2			1			4					
	Nov. 27	13					1	7		4	3	2		1	1	2	4	2					4	4	2	1	2	1		
	Dec. 23	14			1				2		2	2		2	1	1			1		2	6		3		1	1	1		14
1892	Jan 19	1	1					2	2	2			3	2	2	4	1			2	4		4			2			1	
	Feb 15	2			2	1			2			7	5	4	4		4	1	2		4	3			3	3				
	Mch 12	3	2	1		3	3			1		3	3	3	2	2					5	5	2	2	1					
	Apr. 8	4	1		2	6	5	3	2			1	4	3	1					1	2		4		4		3		1	
	May 5	5	2		2		1			3					1			2	1			3	1	1	6	1	3	5		
	May 31	6	5			1	3	2		2		3	4	3	2	3	4	2	3			2	3	2		3	2	1	1	
	June 27	7	3	6	5	1	4	1	6		1	2	4	3	4	5	3	2	4	1	1	2	2	3	3	5	2	3	1	
	July 24	8	1	4	2		1	3	4	2	1	4	2			3	4	1	4	4	3	2	1	5	5	6	3			
	Aug. 19	9	4	4	3	3	2	1	3	1	2	3			2	3	4	2	3	6	5	2	1	1		6	1	4		
	Sep. 15	10	2	2	3	3			3	3		1	1		1	4	1	3	5	4	7	3	2	5	3		2	2	1	
	Oct 12	11	3	2	1		2	1		2			1			3	3	1	3	3	4	3	2	2	2	2	2	3		
	Nov. 7	12	3			1			3	3		1	4	2	1		1	1		4	6	4	5	6	5			1		
	Dec. 4	13	2	4	5	5	2	1	2	1		1	2	2	1		2	3	1			2	2		3				2	
										16														15						

drawing changed from one draftsman to another. The computation sheets were arranged to allow the data for each of the nine zones to be collected together by years for the first compilation. For the second compilation the data belonging to the same zone for the successive years were brought together. Hence, the work of tabulating the data was repeated twice throughout the series. For an ephemeris I used the one already constructed from my computation on the variations of the terrestrial magnetic field, having the period 26.679 days and epoch June 13.72, 1887, as given on page 120, Bulletin No. 21, Solar and Terrestrial Magnetism. This is known to coincide very closely with the period of the *solar rotation at the equator*, and as it was one purpose of this research to test practically the working of this period, it was laid at the basis of the compilation. It makes no difference what ephemeris and period are adopted, since any periodic phenomenon not falling upon that period will show a gradual departure from it by the trailing of the numbers on the sheet from left to right, if the period is too short, or from right to left, if it is too long.

An example of the use of the ephemeris and the result is given in Table 1. One point should be especially noted in this connection, and that is as follows: *The same meridian of the sun is seen twice in a single rotation, first as the eastern limb, and second, thirteen days later, as the western limb.* Whatever may be the intrinsic activity of the sun at a given zone and on a given meridian, that display becomes visible twice, first to the east and second to the west. During the passage of that meridian across the sun's disk the record is wanting so far as this series is concerned, though it could of course be studied otherwise by means of the spectro-heliographic photographs. Thus, as the successive meridians come to the edge of the disk, their output is recorded on the respective drawings. When these are collated with the equatorial period, whatever characteristics they may have which would imply special centers of solar activity will gradually emerge upon the numerical tables. As it is not possible to reproduce these extensive tables in this connection, two specimens of the second collection are shown on Table 1 for the years 1891 and 1892 in succession, and for the zones +50° to +70° and +10° to +30°. Imagine that similar tables for zones +50° to +70° extend from 1871 to 1900, inclusive, except for the gap from 1878-1883, arranged continuously so that the prominence concentration and depletion flows without break on the sheet from year to year. This process is extended to the 9 zones, each 20° in width. In the first collection of the data the highest number was 5, and this was very rarely entered. Since the same area on the sun is seen twice, there may be two entries within the same tabular area on the *first set of sheets*. In the *second set of sheets* these numbers are added together and entered as one, so that occasionally the figures 6, 7, 8 occur, as in Table 1. They represent the largest disturbance occurring in one small area of the sun, as defined by the latitude and longitude thus prescribed. If now the maxima show a tendency to trail across the sheet as indicated by the continuous lines drawn athwart the table, instead of being scattered at random, then this is evidence that the center of eruption itself rotates about the sun at a different rate from that laid down in the assumed ephemeris. From such trails the angular retardation in different zones can be computed with considerable exactness. The reader will not receive a satisfactory impression of the distinctness with which this trailing at different rates in the several zones occurs, without an inspection of the entire series of tables, and it is hoped that they will be published in a special report, as the subject matter is evidently very important and suggestive for the solution of the fundamental problem of the mode of the internal solar circulation.

An examination of these sheets indicates that there is a marked tendency for the numbers to bunch themselves together in a very special manner. Between the successive years there is generally a depletion corresponding with the winter months, while the summer months are relatively full and complete. As pointed out in my paper on Synchronous Changes, this is evidently due to the fact that the relatively cloudy weather in Italy during the winter months made it impossible to secure so many days of observation as during the summer, and I conclude that the apparent concentration of the tables in the summer season is a meteorological effect, and should be treated as such in interpreting the results. At the same time there is a very similar concentration of the numbers along the days of the period, corresponding with a solar rotation, which can not be explained in that way, since it occurs as prominently in summer as in winter. It must apparently be referred back to some solar activity producing prominences on the two opposite sides of the sun. The *maximum numbers* not only trail downwards and to the right on the tables, but the *lines of maximum* also drift across the tables to the left, thus indicating retardation in the higher latitudes relative to the adopted equatorial period.

It may be mentioned in passing that this increase of activity of the sun on two opposite sides of its mass, as if a certain diameter had greater energy than the one at right angles to it, has already been detected by me in the meteorological field of the earth's atmosphere, and also in the terrestrial magnetic field, as shown on pages 91 and 92 of my Eclipse Meteorology and Allied Problems, and elsewhere. This persistent excess of outflowing energy on two opposite sides of the sun suggests the possibility that *the sun should be regarded as an incipient binary star*,[12] where the dumbbell figure of revolution prevails instead of the spheroidal. If this is really the case, and the evidence suggests it, then there would be a reason for the existence of the two primary centers of activity in the sun, instead of its having a single center. Some double acting system appears to impress itself generally upon the solar cosmical relations. From this we should expect to find that the sun has two magnetic and two meteorological systems, interacting so as to form the configuration of the external field as measured at the earth. There would then be sufficient ground for a differential action in the terrestrial pressures and temperatures, as detected in the discussion of such data by many students.

This view is quite in harmony with the well known fact of the existence of numerous binary systems of suns more or less widely separated, and it can not be regarded as unlikely that the sun is actually developing in this way. The enormous mass of the sun would seem to entice its constituents to group themselves preferably about two centers for the physical processes involved in circulation and radiation, rather than about one, and I suspect that this is the correct explanation of several well known phenomena.

DISCUSSION OF THE OBSERVATIONS.

On Table 1 are given some examples of the slope of the line of maximum frequency numbers in successive years. These were drawn originally by a careful examination of the entire set of figures, and an effort was made to locate the line along the maximum numbers so as to balance as nearly as possible the entire system on either side of it. Some regard was paid to the average trend of the lines in the other portions of the same zone, whereby one's judgment was guided in cases of doubt. Entire impartiality was exercised as far as practicable, and the results now about to be described were entirely unexpected. It would perhaps be preferable to utilize least square methods, if one could afford so great labor. The lines are all numbered, as 16, 17 in the zone + 50° to + 70°, which are complete; those in zone + 10° to + 30°, namely

[12] Compare Figures of Equilibrium of Rotating Masses of Fluids. By G. H. Darwin, Proc. Roy. Soc. Vol. XLII. 1887, p. 359. Thomson and Tait, Nat. Phil. Vol. I, part 2, pp. 330-335.

14, 15, 16, are fragmentary on Table 1. We now count the number of days which have elapsed for a certain number of periods, in order to find the average rate of retardation per rotation of 26.68 days. Thus, for the line 16, zone + 50° to + 70°, about 12 periods elapsed, beginning with period 2 and ending with period 14, while the line was trailing, or the period was retarded, 26.7 days. Hence, 26.7 ÷ 12 = 2.225 days retardation per period of 26.68 days, so that the rotation period in that zone is 28.905 days. Similarly, line 17 gives a retardation of 26.2 days in 11 periods. Hence, 26.2 ÷ 11 = 2.382. These two values are entered in the proper place on Table 2. The results have been grouped by years where the solar energy is passing from maximum to minimum, 1871–1877, 1884–1888, 1894–1900, and again where it is passing from minimum to maximum (1878–1883, lacking), 1889–1893, so as to study the effect of this variation in the retardation; but the unfortunate gap 1878–1883 prevents a satisfactory comparison between these two groups. The several zones are given separately for each hemisphere, and the successive trails can be readily scrutinized.

The first column of Table 2 contains the years of the groups; the second the slope of the 11-year curve, roughly; the third the number of the line in the zone; the fourth the number of periods elapsed; the fifth the number of days of retardation in these periods; the sixth the average retardation in days on the 26.68-day period. The mean retardation for each zone in both hemispheres is given, and has been collected in Table 3. It was necessary to assume that the mean latitude of the occurrence of the prominences is in the middle of each zone, though this can not be strictly correct. It would require very extensive computation to determine the mean latitude of

TABLE 2.—*Retardation of the sun in different latitudes as derived from the prominence frequency in longitude.*

Years.	Slope.	Line.	Periods.	Days.	Retardation.	Line.	Periods.	Days.	Retardation.
		Zone + 10° to — 10°.							
1871–1877	Max.-Min.	1	90	9.0	0.100	...	...	...	...
		2	90	9.0	0.100	...	...	...	...
1884–1888	Max.-Min.	3	69	6.5	0.094	...	...	...	...
		4	69	7.4	0.107	...	...	...	...
1889–1893	Min.-Max.	5	68	5.2	0.077	...	...	...	...
		6	68	6.0	0.088	...	...	...	...
1894–1900	Max.-Min.	7	96	11.4	0.119	...	...	...	...
		8	69	8.2	0.119	...	...	...	...
		Mean.........			0.101				
		Zone + 10° to + 30°.				Zone — 10° to — 30°.			
1871–1877	Max.-Min.	1	18	12.8	0.711	1	15	12.5	0.833
		2	41	28.2	0.688	2	28	22.1	0.789
		3	39	26.1	0.669	3	38	26.5	0.697
		4	35	25.3	0.723	4	39	27.0	0.692
		5	25	20.2	0.808	5	37	27.0	0.729
		6	26	17.8	0.684	6	26	19.0	0.731
		7	9	6.0	0.666	7	10	7.3	0.730
1884–1888	Max.-Min.	8	19	14.0	0.737	8	16	14.0	0.875
		9	34	26.0	0.765	9	31	27.0	0.873
		10	35	26.0	0.743	10	33	26.7	0.809
		11	35	25.0	0.714	11	35	26.5	0.803
		12	10	7.2	0.720	12	17	14.0	0.824
1889–1893	Min.-Max.	13	18	16.2	0.900	13	16	13.6	0.850
		14	31	26.7	0.863	14	34	26.8	0.788
		15	31	26.2	0.845	15	34	26.7	0.785
		16	23	19.0	0.826	16	27	22.0	0.815
1894–1900	Max.-Min.	17	33	26.3	0.797	17	33	26.4	0.800
		18	37	26.7	0.722	18	35	27.0	0.722
		19	35	27.8	0.794	19	34	26.6	0.783
		20	34	26.6	0.783	20	36	28.0	0.778
		21	28	20.7	0.739	21	35	26.8	0.766
		...	...	...	...	22	34	24.0	0.706
		...	...	...	...	23	13	9.8	0.753
		Mean.........			0.757	Mean.........			0.782

TABLE 2.—*Retardation of the sun in different latitudes as derived from the prominence frequency in longitude*—Continued.

Years.	Slope.	Line.	Periods.	Days.	Retardation.	Line.	Periods.	Days.	Retardation.
		Zone + 30° to + 50°.				Zone — 30° to — 50°.			
1871–1877	Max.-Min.	1	15	21.0	1.400	1	18	19.8	1.100
		2	20	27.0	1.350	2	26	27.0	1.038
		3	20	27.4	1.370	3	27	26.4	0.978
		4	19	28.0	1.474	4	25	27.3	1.092
		5	18	27.4	1.522	5	24	26.7	1.112
		6	18	27.3	1.517	6	27	27.7	1.026
		7	24	33.0	1.375	7	24	24.6	1.025
		8	21	25.3	1.205	8	10	9.9	0.990
1884–1888	Max.-Min.	9	20	24.2	1.210	9	15	14.5	0.967
		10	21	27.0	1.286	10	28	26.0	0.929
		11	22	27.2	1.236	11	27	23.6	0.874
		12	23	27.5	1.196	12	32	27.2	0.850
		13	21	27.5	1.309	13	29	27.2	0.938
		14	19	26.0	1.368	...	...	...	...
1889–1893	Min.-Max.	15	22	27.0	1.227	14	28	27.0	0.964
		16	23	27.0	1.174	15	29	27.8	0.958
		17	24	27.0	1.125	16	32	27.2	0.850
		18	24	27.5	1.146	17	27	27.2	1.007
		19	25	27.7	1.108	18	26	26.0	1.000
		20	26	27.0	1.038	...	...	...	...
1894–1900	Max.-Min.	21	27	27.4	1.015	19	30	27.8	0.927
		22	26	27.0	1.038	20	29	27.2	0.938
		23	30	27.0	0.900	21	23	26.0	1.130
		24	35	26.5	0.786	22	25	27.0	1.080
		25	28	26.2	0.936	23	29	28.0	0.965
		26	27	23.8	0.881	24	30	27.0	0.900
		Mean.........			1.192	Mean.........			0.989
		Zone + 50° to + 70°.				Zone — 50° to — 70°.			
1871–1877	Max.-Min.	1	13	27.7	2.131	1	11	20.6	1.873
		2	13	27.0	2.077	2	15	26.6	1.773
		3	14	27.0	1.928	3	13	27.0	2.077
		4	11	27.3	2.482	4	12	27.0	2.250
		5	13	27.5	2.115	5	15	27.4	1.827
		6	15	27.0	1.800	6	15	26.8	1.787
		7	19	27.3	1.437	7	9	19.0	2.111
		8	8	14.0	1.750	...	...	...	...
1884–1888	Max.-Min.	9	18	27.7	1.539	8	10	26.0	2.600
		10	18	28.0	1.556	9	10	26.2	2.620
		11	21	27.6	1.314	10	12	27.8	2.317
		12	19	27.3	1.437	11	13	26.4	2.031
		13	14	27.7	1.979	12	11	26.5	2.409
1889–1893	Min.-Max.	14	14	27.7	1.979	13	11	26.0	2.364
		15	15	27.4	1.827	14	12	26.6	2.217
		16	12	26.7	2.225	15	11	27.8	2.527
		17	11	26.2	2.382	16	11	27.0	2.455
		18	13	28.0	2.154	17	11	26.4	2.400
		...	...	...	...	18	12	27.5	2.292
1894–1900	Max.-Min.	19	15	27.0	1.800	19	13	26.0	2.000
		20	13	27.0	2.769	20	11	27.0	2.455
		21	9	26.0	2.889	21	10	27.5	2.750
		22	10	27.4	2.740	22	11	27.0	2.455
		23	10	27.5	2.750	23	15	26.4	1.760
		24	11	27.5	2.500	24	18	27.6	1.533
		25	12	27.0	2.250	25	17	27.7	1.629
		Mean.........			2.072	Mean.........			2.180

occurrence of the several zones more accurately. The aspect of the path of maximum frequency as given on fig. 4 of my previous article entitled Synchronous Changes,[13] is favorable to this simple assumption.

TABLE 3.—*Mean retardation by zones.*

Mean latitude.	Retardation. North.	Retardation. South.	Retardation. Mean.	Mean period.
°				
0	0.000	0.000	0.000	26.68
5	0.101	0.101	0.101	26.78
20	0.757	0.782	0.770	27.45
40	1.192	0.989	1.091	27.77
60	2.072	2.180	2.126	28.81

A careful examination of the individual determinations of the retardations in the several zones shows that there is a wide fluctuation which increases in magnitude from the equator toward the poles. In order to obtain a clear idea of the law of the retardations these results have been plotted on fig. 2.

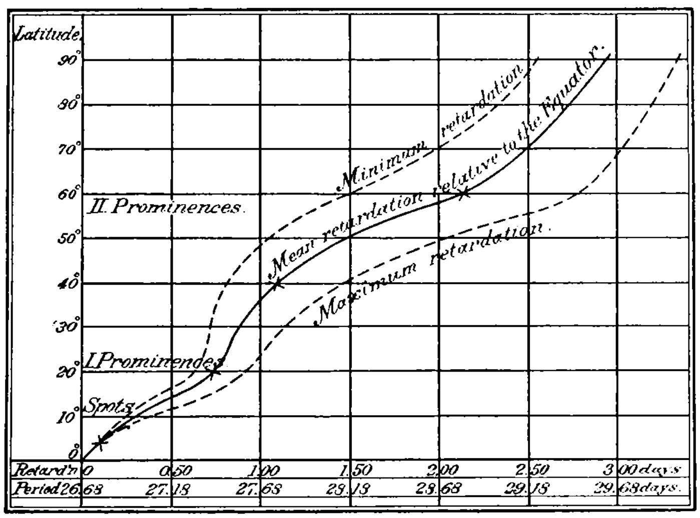

FIG. 2.—Periods of rotation of the solar photosphere derived from the prominence frequency in different zones.

TABLE 4.—*Bigelow's rotation periods.*

Latitude.	Daily angular velocity.	Sidereal period.	Synodic period.
°	′	*Days.*	*Days.*
Pole 90	788	27.40	29.63
85	790	27.32	29.54
80	793	27.23	29.43
75	795	27.15	29.33
70	799	27.03	29.18
65	804	26.86	29.00
60	809	26.70	28.81
II Pr. 55	815	26.50	28.58
50	824	26.20	28.23
45	832	25.94	27.93
40	837	25.81	27.77
35	840	25.71	27.66
30	842	25.66	27.60
25	845	25.57	27.50
I Pr. 20	846	25.53	27.45
15	852	25.36	27.26
Spots 10	859	25.15	27.00
5	866	24.95	26.78
Equator 0	869	24.86	26.68

[13] Monthly Weather Review, January, 1903, Vol. XXXI, p. 17.

The mean retardation, with an approximate maximum and minimum retardation, is there indicated. From the mean line I have scaled off the corresponding synodic periods for every five degrees of latitude, as given in Table 4, and have computed the sidereal period and the daily angular velocity, X, in minutes of arc belonging to them. These transformations can readily be made by interpolations from Table 5.

The latitude at which the maximum of spots is commonly observed, and also the latitude of the maxima I and II of prominence frequency, are indicated in Table 4 and fig. 2 by the terms "Spots," "I Pr.," "II Pr."

TABLE 5.—*Transformations of the daily angular velocity into sidereal and synodic periods.*

T=sidereal period of the sun; E=sidereal period of the earth; S=synodic period of the sun. Then we have $\frac{1}{T}-\frac{1}{E}=\frac{1}{S}=\kappa-n$.

Daily X	T	$\frac{1}{T}=\kappa$	$\frac{1}{E}=n$	$\frac{1}{S}$	S
′					
900	24.00	0.04167	0.00274	0.03893	25.69
895	24.13	0.04144		0.03870	25.84
890	24.27	0.04120		0.03846	26.00
885	24.41	0.04097		0.03823	26.16
880	24.55	0.04074		0.03800	26.32
875	24.69	0.04051		0.03777	26.48
870	24.83	0.04028		0.03754	26.64
865	24.97	0.04005		0.03731	26.80
860	25.12	0.03982		0.03708	26.97
855	25.26	0.03958		0.03684	27.14
850	25.41	0.03935		0.03661	27.32
845	25.56	0.03912		0.03638	27.49
840	25.71	0.03889		0.03615	27.66
835	25.87	0.03867		0.03592	27.84
830	26.02	0.03843		0.03569	28.01
825	26.18	0.03819		0.03545	28.21
820	26.34	0.03796		0.03522	28.39
815	26.50	0.03773		0.03499	28.58
810	26.67	0.03750		0.03476	28.77
805	26.83	0.03727		0.03453	28.96
800	27.00	0.03704		0.03430	29.15
795	27.17	0.03681		0.03407	29.35
790	27.34	0.03657		0.03383	29.56
785	27.52	0.03634		0.03360	29.76

It should be noted that the mean retardation does not follow a regular slope, or a simple curve that can be reduced to an analytic function. From latitude 20° to 40° there is a smaller inclination than on the slopes between 0° and 20°, or on those between 40° and 60°. In fig. 2 the line has been extended to 90°, that is to the pole, but it is unknown beyond 70°, since the polar zones were too irregular to permit any use of this method. It is probable that a continuous line, as indicated, is nearly correct.

In order to compare my result with some well known rotation periods, (taken conveniently from Miss Clerke's Problems in Astrophysics, p. 146), the following compilation is introduced:

Heliographic latitude.	Spots.	Prominences. (Bigelow).	Faculæ.
°			
0	25.09	24.86	24.66
15	25.44	25.36	25.26
30	25.81	25.66	25.48

From this it appears that my prominence rotations lie midway between those of the spots and the faculæ. Duner's rotations for the reversing layer, as quoted by Miss Clerke, are apparently impossible. The determinations of the rotation period as given by the well-known formulæ of Carrington, Spoerer, Faye, and Tisserand are found in Table 6. These periods begin to depart from the rotations as found from the prominences after leaving the latitude of 20°.

TABLE 6.—*Several denominations of the rotation periods of the solar spots in different latitudes.*

	Carrington.			Spoerer.		
d	*X*	*T*	*S*	*X*	*T*	*S*
°	′			′		
0	865	24.97	26.80	877	24.65	26.42
5	863	25.03	26.90	864	25.00	26.83
10	857	25.20	27.07	853	25.32	27.21
15	849	25.44	27.35	842	25.65	27.59
20	840	25.71	27.66	833	25.93	27.91
25	828	26.08	28.09	825	26.18	28.21
30	816	26.47	28.54	819	26.37	28.43
35	803	26.93	29.04	814	26.53	28.62
40	789	27.38	29.60	810	26.67	28.77
	Faye.			Tisserand.		
d	*X*	*T*	*S*	*X*	*T*	*S*
°	′			′		
0	862	25.06	26.90	858	25.18	27.04
5	861	25.09	26.93	857	25.20	27.07
10	856	25.23	27.11	853	25.32	27.21
15	850	25.41	27.32	847	25.50	27.42
20	840	25.71	27.66	840	25.71	27.66
25	829	26.05	28.05	830	26.02	28.01
30	815	26.50	28.58	819	26.37	28.43
35	801	26.97	29.11	806	26.80	28.92
40	785	27.52	29.76	793	27.24	29.43

It is proper to remark that the agreement in low latitudes, between the periods obtained from the prominences, the spots, and the faculæ is not unfavorable to a feeling of confidence in the results obtained by the prominence method in higher latitudes. This is perhaps strengthened by the further developments which are indicated in the next section.

THE DIFFERENTIAL CIRCULATION WITHIN THE SUN.

In order to study more minutely the meaning of the fluctuations in the relative retardations given for successive lines in Table 2, it is seen that we have practically obtained a value of the retardation for each year of the interval 1871–1900, except for the gap 1878–1883, and that by plotting these as ordinates on a diagram whose abscissas are the years, a curve of relative retardation in the several zones can be constructed. Fig. 3 exhibits these data in a graphical form. Thus, in the northern hemisphere, for the zone + 50° to + 70°, the ordinates in Table 2, beginning with that for 1871, read 2.13, 2.08, 1.93, ... 2.25, and these form the successive points of the retardation curve. In the upper section of the diagram marked "Prominence frequency" is reproduced the curve of average prominence frequency for the entire sun, which is the mean curve of the zonal system shown on fig. 2 of my paper on Synchronous Changes,[14] and is also reproduced at the head of fig. 28 of my paper, A Contribution to Cosmical Meteorology.[15] An inspection of the curves of fig. 3, shows plainly three important facts of fundamental significance: (1) the retardations relative to the equatorial period of rotation, 26.68 days, increase toward the poles; (2) the irregularities in the observed retardations are very much greater in the polar than in the equatorial zones; (3) these irregularities in the retardation do not appear to be accidental, but they synchronize closely with the variations in the frequency of the prominences. The value of this last inference is very great, in view of the other facts brought out in various portions of my research. Using this prominence curve as the standard of reference we have already proved the following facts: (1) The elements of the earth's magnetic field fluctuate

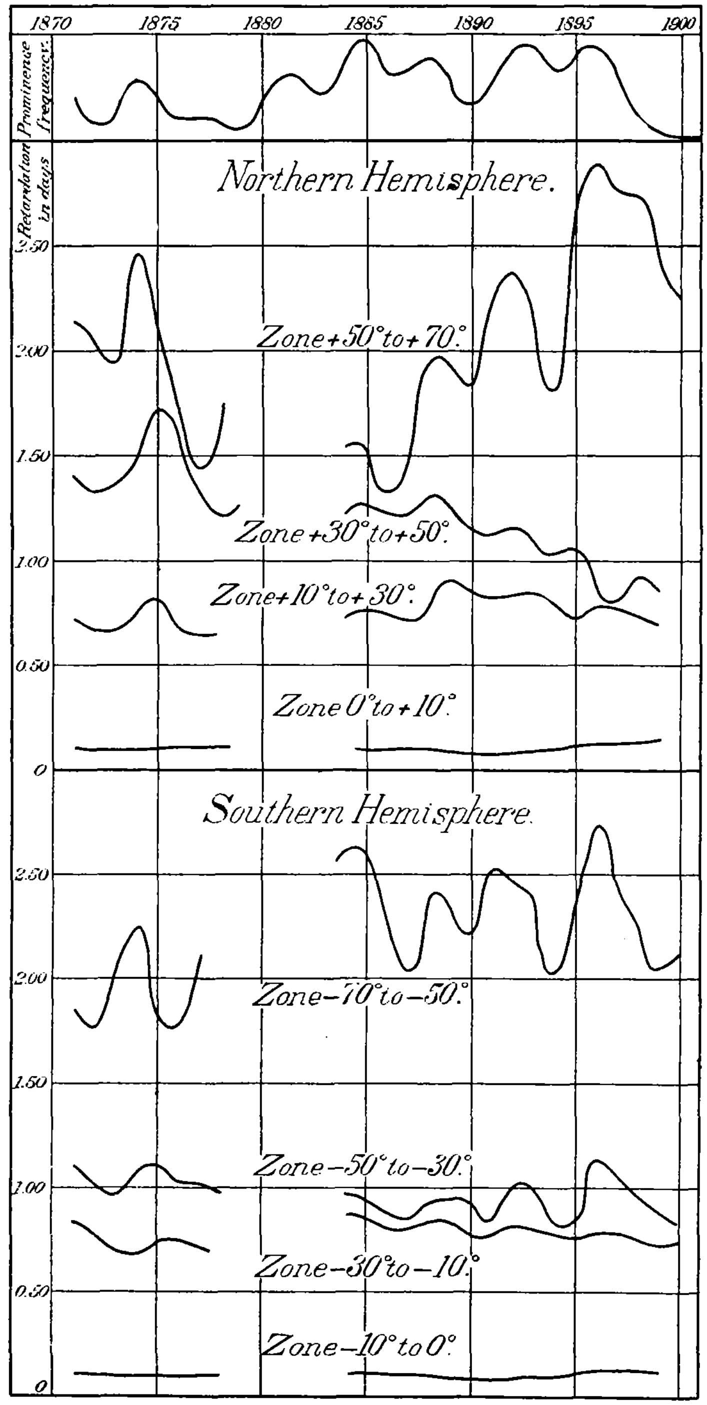

FIG. 3.—Variable retardations in the periods of rotation of the solar photosphere.

with it annually in synchronism; (2) the terrestrial temperatures and barometric pressures synchronize with it, as will be shown conclusively in my next paper, in the MONTHLY WEATHER REVIEW for November, 1903; (3) the internal circulations of the sun, as recorded in the rotational velocities of the photosphere, also synchronize with the same curve. This exhibit binds the entire solar and terrestrial atmospheres in one synchronous circulation, and it therefore places the entire subject

[14] Monthly Weather Review, January, 1903, Vol. XXXI, p. 10.
[15] Monthly Weather Review, July, 1902, Vol. XXX, p. 352.

of cosmical meteorology upon a satisfactory basis, entirely in harmony with the procedure marked out in previous papers.

While it can not be supposed that this discussion of the solar prominence frequency in longitude gives us final quantitative results on the rotation phenomena of various zones, yet the line of argument is sufficiently sustained to warrant further extensions of the research. We have shown that the solar angular velocity diminishes from the equator toward the poles at a certain rate, as on fig. 1 for example, or as on fig 4.

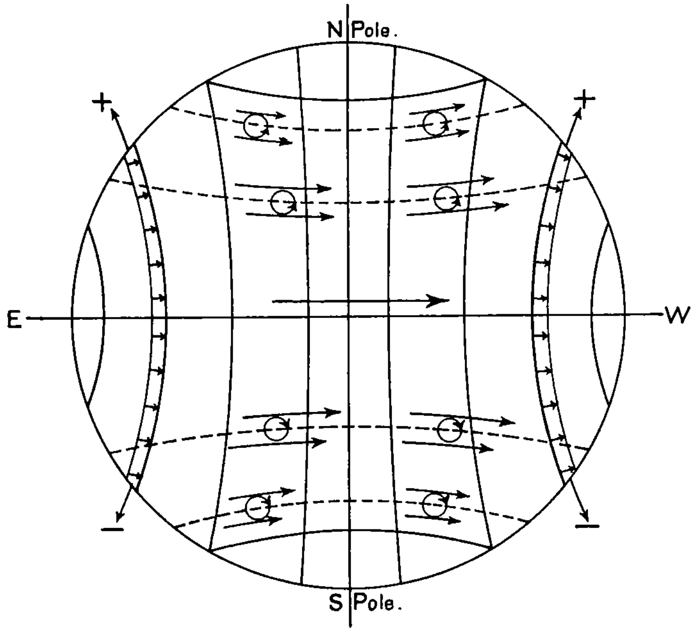

FIG. 4.—Formation of vortices in the solar mass by differential rotations.

This is in harmony with the von Helmholtz-Emden equations for a rotating mass hot at the center and cooling toward the surface.[16] In such a mass there are discontinuous concave cylindrical surfaces coaxial with the axis of rotation, the equatorial parts being nearer the axis than are the polar parts. This also implies that the polar regions of the sun are warmer than the equatorial by reason of the currents from the center toward the poles. At a surface of discontinuity, on each side of which the pressure is the same, but the temperature and angular momentum different, as where a rapidly moving current flows over a more slowly moving current in the earth's atmosphere, the conditions are favorable for forming vortex tubes, terminating on the surface, but extending through the mass of the sun. They are right-handed in the northern hemisphere and left-handed in the southern hemisphere, for convective actions from the equator toward the poles. If vortices are thus formed in the sun, so far as the state of its material permits, then the solar mass is in fact in a polarized state, the internal matter tending to rotate throughout the globe around such lines as are the generators of the required discontinuous surfaces. The turbulent conditions of internal circulation tend to a lawful disposition by the regulative action of a hot mass gravitating to a center by its own internal forces and emitting heat through these processes of circulation accompanied by polarization and rotating vortex tubes. The contents of a tube must be made up of molecules and atoms more or less charged with electricity, and the necessary rotatory motion produces Amperean electric currents which are a sufficient cause for the generation of a true magnetic field, positive on the northern and negative on the southern hemisphere of the sun. This conforms to the result reached years ago by my analysis of the terrestrial magnetic field, which showed that the earth appears to be immersed in a magnetic field perpendicular to the plane of the ecliptic and positive to the north of it. Variable circulation within the solar mass would display itself in corresponding changes in the rotation of the discontinuous surfaces, in the vortices carrying electrical charges, in the external magnetic field, in the number of prominences, faculae, and spots, in the earth's magnetic and electric fields, and in the terrestrial temperatures and pressures. Synchronism having thus been established throughout this vast complex cosmical system and referred back to fundamental thermodynamic and hydrodynamic laws, it becomes possible to make further advances in the problems of solar physics. Thus, the curvature of the internal lines can be studied in different parts of the meridian section on passing from the surface of the sun to internal parts by means of the vortex law of constant angular momenta, $\Omega = \omega \varpi^2$, under the assigned thermal conditions. We shall make an attempt to do this in a report which will contain the tabular data in full upon which these deductions are based.

If it is true that large cosmical cooling masses in rotation contain a polarized or vortical internal structure which is the basis of a magnetic field, then it follows that this is the explanation of the earth's magnetism as well as of the magnetism of the sun. Hence, all stars are magnetized spheres, and their relative magnetism would be a measure of the activity of their internal circulations. Thus, the relative intensity of the earth's and the sun's magnetization becomes a measure of the internal vortical circulation in polarized tubes, and the variations of the earth's magnetic field have a cosmical significance, not only as to the direct action of the sun as a great rotating variable magnet, but as a measure of the forces which go to make up the solar output in several manifestations of energy. The summary of this line of thought may be found in chapter 4 of my "Eclipse Meteorology." It is proper to renew my objection to the results derived by other investigators for any solar rotation period which is shorter than 26.68 days, because it does not seem to be possible in view of the above analysis of solar conditions. Thus, we must reject Spoerer, 26.32; Broun, 25.92, 25.86, and 25.83; Hornstein, 26.39, 26.03, 26.24, and 25.82; Liznar, 26.05 and 25.96; Müller, 25.66, 25.79, 25.86, 25.87, and 25.47; von Bezold, 25.84; Hamberg, 25.84; Ekholm and Arrhenius, 25.93; Schuster, 25.809 or 25.825. The numerous computations, giving results so widely different from that apparently ruling in the sun as derived from observations upon its own material, seem to indicate that the application of these several methods of computation to terrestrial data raises grave doubts as to their value. There are numerous difficulties in applying least square methods to solar-terrestrial data in the present state of our science. The great fluctuations going on within the solar mass tend to mask the fundamental law until it has been derived, at least approximately, by simpler methods. But the evidence is very positive that the equatorial period of 26.68 days is the shortest one actually prevailing in any portion of the mass of the sun.

[16] See Eclipse Meteorology, pages 70 and 71.

CLIMATOLOGY OF COSTA RICA.

Communicated by Mr. H. PITTIER, Director, Physical Geographic Institute.

[For tables see the last page of this REVIEW preceding the charts.]

Notes on the weather.—On the Pacific slope the rainfall was generally less than the average, although enough to cause numerous slides along the few railways to the western coast. In San José pressure and temperature were above the normal and relative humidity slightly under it. Rainfall almost normal and unequally distributed through the month. Sunshine one hundred and seventy-nine hours against one hundred and thirty-six. The marked alternation of hot sun and violent showers caused a good deal of damage to the coffee crop, part of which has thus been "frozen" (helado). On the Atlantic