Some Notes on Solar Research*

By

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Abstracts

In 1923, when I was studying solar phenomena from the data observed at Mt. Wilson Observatory, I found a peculiar relation between the distance of the positive and negative magnetic poles and the maximum intensity of the magnetic field in the bipolar sun-spot. Generally the relation is linear, the field intensity increasing with the distance between the poles; but there is apparently a lower limit of the latter for a range of the former, so that the graphical form of the relation as a whole is more or less logarithmic.

On the other hand, I found a tendency for the distance between the magnetic poles to occur in a wider range if a spot is nearer the solar equator. The evidences are similar in both northern and southern hemispheres.

There is no logical connection between the above two phenomena. But, if we assume an hypothetical idea that the bipolarity of the sun-spot is a physical consequence of the velocity changes between the successive layers of the solar atmosphere, then the first phenomenon will suggest a discontinuity of the circulating velocity in a certain depth of the atmosphere, and the second phenomenon seems to indicate a gradual change of the relative depths and the radial distribution of the layer velocities according to heliographical latitudes. It seems to me that the depths of the atmosphere considered herewith are beyond the range of penetration with spectroscopic or other instrumental powers, so that the evidences above mentioned cannot be examined otherwise than by heliographic study.

1. *Introduction.* In 1923 I spent some months at the Mount Wilson Observatory, and carried out a research to examine a possible relation

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between the variable "solar constant" and some heliographic disturbances. The materials then used were, on the one hand, the most recent values of the solar constant observed under Dr. C. G. Abbot, and on the other hand, the spectroheliographic records as well as the heliomagnetic observations obtained by Mt. Wilson observers.*

The present notes are some of the casual results obtained during the above-mentioned examinations of the materials, and principally from the visual observations of the magnetic properties of sun-spots which had been carried out as routine work, since some years ago, at Mt. Wilson by Mr. F. Ellerman and others.

2. *Polar distances and the magnetic field intensity of bipolar sun-spots.* It is at present widely accepted, following Dr. G. E. Hale's brilliant researches, that a typical disturbance on the solar surface consists of a pair of sun-spots which form a group and are oppositely polarized in magnetism. The "following member" of the sun-spot group is usually not so stable as the "preceding" one in its heliographic configurations. But according to my observations, the distance between the two dominating centers of magnetic fields is fairly durable as well as the field intensity of the preceding spot. Consequently I took the heliographical distance of such bipolar spots as abscissae, and the magnetic field intensity of the "preceding" spot as ordinates in a diagram, just to see their mutual relation, if any, graphically. Fig. 1 gives the feature. In my examinations of the original observations I made no statistical treatment, but selected those data of the day on which the solar disturbance examined reached a good degree of development and also became convenient for my quantitative estimation by approaching as near as possible to the central meridian of the solar disc. Some, however, had to be examined when they were not near the meridian because of their short duration or other circumstances. Accordingly I assigned proper weights to the quantities here estimated. In Fig. 1, the circles represent those which were observed within 1 centimeter of the central meridian of the original 43-cm solar disc, the dots those which were between 1 to 10 centimeters from the meridian, and the crosses, those which were more than 10 centimeters distant from it. A possible relation is apparent, although it is not very clear

* The results of this research has been published fully in Memoirs of the College of Science, Kyoto Imperial University **11**, 233 (1928); and its somewhat abridged report was published in Monthly Notices, Royal Astronomical Society, Vol. LXXXV, No. 1, (November 1924), pp. 71-78.

and definite. As a whole a linear relation seems to hold. But, if we take the relative weights into account, a greater or less curvature of the mean curve of regression is probable, so that a formula:

$$H-H_0=M.\log\,(\rho-\rho_0) \qquad (1)$$

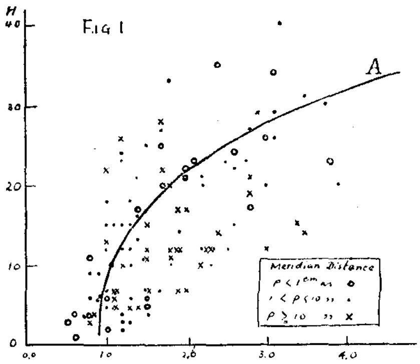
is suggested, where, H, the magnetic field intensity, ρ, the distance between the two spots, and H_0, ρ_0, and M are constants.

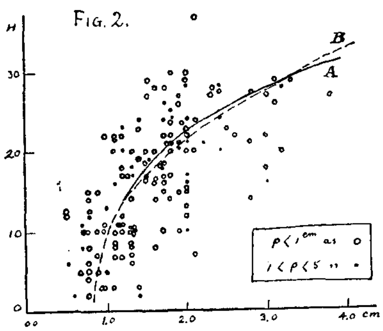
Fig. 1 was obtained by using the materials from the original observations of sun-spot magnetism made in the course of two and a half years, January 1921—September 1923, which should be considered to include the time when the solar activity is "minimum." Next, I treated similarly the original observations from another period of one year, July 1917—July 1918, which is representative of the "maximum" activity of the solar surface. The result is shown in Fig. 2. Here the circles denote those which were estimated within 1 cm. of the solar meridian, while the dots represent those which were between 1 and 5 cms. from the meridian. The tendency is generally the same as in Fig. 1. Moreover, the mean curve of both diagrams runs practically through the same points: in Fig. 2 the broken line B represents the mean curve of points in the same diagram, and the line A denotes the points on which the mean curve of the quantities of Fig. 1 runs.

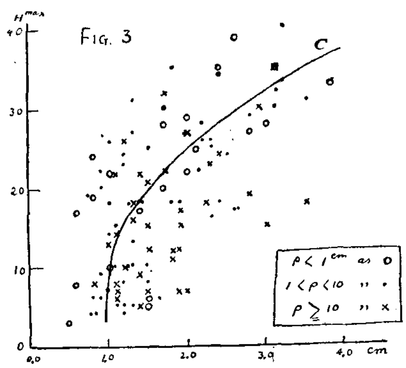
It is true that these "mean curves" should not be too strictly considered in the physical sense; they are no more than a mathematical conventionalisation of the phenomenal appearance. There are wide deviations of individual points from these curves as seen in the two diagrams, and also a physical interpretation of the general character of these curves should be made sooner or later.

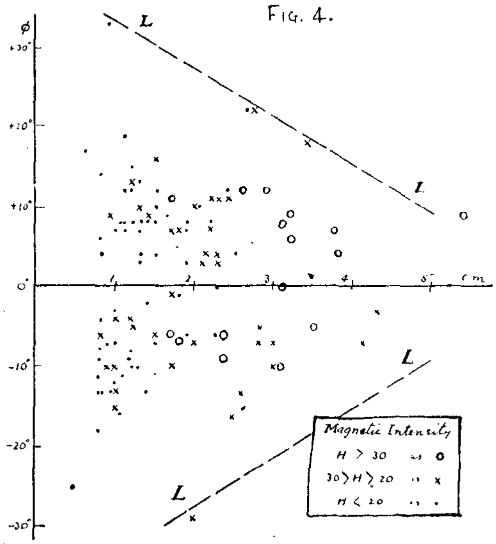
Nevertheless, it is too remarkable to be neglected in this connection that there is practically a lower limit in the mutual distance between the two spots in a bipolar sun-spot group, as is seen in the two diagrams: in both cases 0.5 cm. is the least distance ever observed, and yet this is clearly not due to observational difficulties, for the said limit is well within the possibility of visual examination.

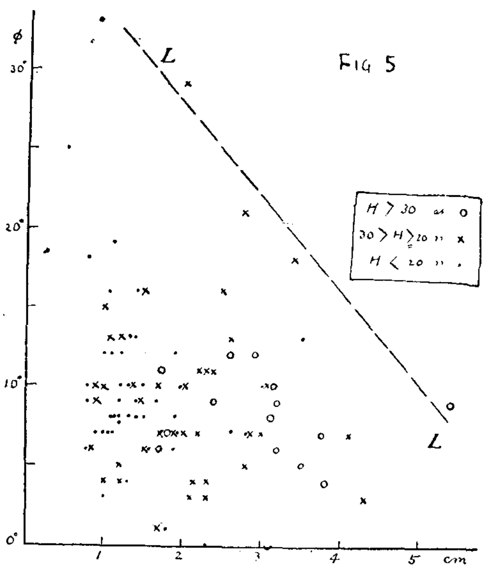
In Fig. 3 I tried to plot the quantities of Fig. 1, retaining the same values for the abscissae, but taking for the ordinates the largest values of the magnetic field intensities ever observed in each sun-spot group, although these largest possible values were not always observed simultaneously with the corresponding interpolar distances. In its general features Fig. 3 is not very remarkably different from the other two, except that there is every possible augumentation of the ordinates. But a close examination of the diagram shows, especially in the most weighted quantities, the curvature of the mean curve more clearly, and at the same time it reveals a slightly wider range, in ordinate, of occurrence of the lowest values of the polar distances.











3. *Polar distances and the Holiographic latitudes of bipolar sun-spots.* Next, I took the heliographic latitudes of the sun-spot group as ordinates, while the abscissae denoting the interpolar distances remained the same as in Fig. 1. The new diagram thus obtained is shown in Fig. 4. In this case, the circles represent those whose magnetic field intensities are larger than 30 in Mr. Ellerman's scale, (in Mr. Ellerman's scale of the magnetic intensity unity is about 100 gausses,) the crosses, those between 20 and 30, and the dots, those which are less than 20 units. In Fig. 4 we see that the whole diagram is symmetrical about the solar equator, and also there is clearly and decidedly a wider range of inter-polar distance occuring in lower heliographic latitudes than in higher latitudes. If we combine all the materials into a simpler diagram neglecting the distinction of north and south in the solar latitude, we get Fig. 5. The feature just mentioned is here more conspicuous, and the general tendency of a wider pair of sun-spots to occur in lower latitudes is so clear that a straight light line LL arbitrarily drawn upon the diagram appears a practical boundary of occurrence of the quantities.

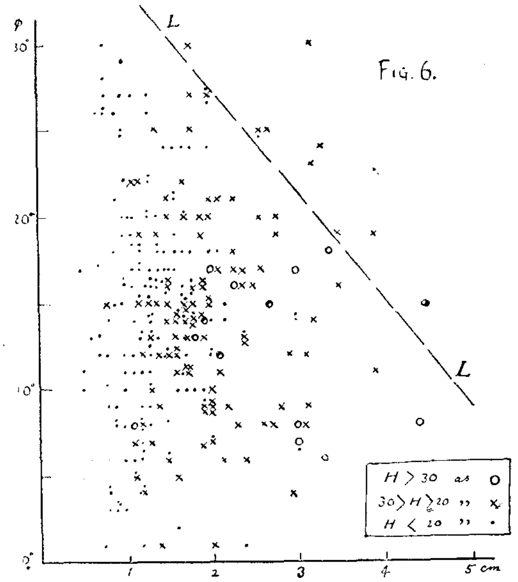


Fig. 6 is similar to Fig. 5, the material being however taken from ths years 1917–1918. Owing to the difference in the periods of solar activity, the distribution of the frequency of sun-spots in various latitudes differs in Figs. 5 and 6, which are widely recognized nowadays. Still the boundary line, which has been suggested in Fig. 5 to include all points between itself and the coordinate axes, appears to hold true just the same when it is *reproduced* in its exact position, as is shown in Fig. 6, limiting practically all points.

4. *Some physical suggestions from the above results.* There is apparently no logical connection between the two kinds of phenomena above mentioned. Now, if we assume an idea following Dr. G. E.

Hale that the bipolarity of sun-spot groups is caused by velocity-differences of successive layers of the solar atmosphere, then :

$$\frac{dv}{dr}\,dr = K.\ d\rho \tag{2}$$

where v means current velocity of a solar atmospheric layer whose distance from the sun's center is r, and K a constant, while ρ means the distance between the two components of the bipolar group as previously mentioned. But, from (1)

$$d\rho = N.\ E^{H}.\ dH,$$

where $$N = \frac{1}{M}\cdot\frac{1}{E^{H_0}},$$

and $$E = e^{1/M}.$$

Hence, $$\int \frac{dv}{dr}.\ dr = N\int E^{H}.dH.$$

If we assume that the correlation between the inter-polar distance and the magnetic-field intensity is linear, then

$$\frac{dv}{dr} = \text{constant},\ P\ \text{say},$$

and consequently the polar distance becomes

$$P(r-r_0) = N.E^{H} = N.e^{H/M}$$

or $$H = \text{constant.}\ \log(r-r_0).$$

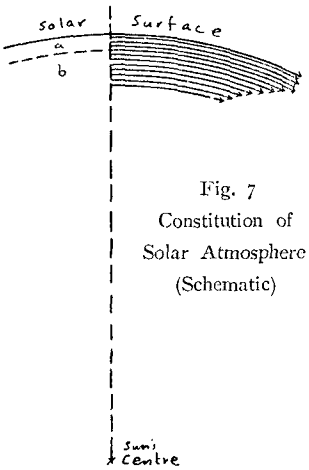


Fig. 7
Constitution of Solar Atmosphere (Schematic)

a = Layers of Constant Velocity
b = " " Varying "

But, as shown in Figs. 1 and 2, there is a lower limit of ρ, which is approximately 0.5 cm. in our scale, and this fact suggests that within a certain depth of the solar atmosphere from the uppermost surface we should have

$$\frac{dv}{dr} = 0.$$

The accompanying Fig. 7 shows the schematic view of a vertical section of the atmospheric currents of the sun. I cannot say how deep is the layer of discontinuity of the velocity, except a rough estimation of the order of

$$\frac{0.5}{43.0} = \frac{1}{90}$$

of the solar diameter.

Another fact revealed in Figs. 5 and 6 is that there a continuous variation of distribution of the atmospheric velocities according to heliographical latitudes, although the depth of the constant velocity in the uppermost part of the atmosphere is sensibly constant.

It seems to me that these considerations will be important in the theoretical treatment of the constitution of the solar atmosphere.

Harvard College Observatory,

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