THE DIRECTION OF ROTATION OF SUN-SPOT VORTICES

By George E. Hale

MOUNT WILSON SOLAR OBSERVATORY, CARNEGIE INSTITUTION OF WASHINGTON

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Whirling storms in the earth's atmosphere, from the extensive and moderate cyclone to the small and destructive tornado, follow a well-known law of rotation: right-handed or clockwise in the southern hemisphere and counter-clockwise in the northern. These directions are easily explained by the increasing eastward velocity of the air from pole to equator. As sun-spots are vortex phenomena, analogous in many respects to tornadoes, it is interesting to inquire as to the law of their rotation, since this may throw light on their nature and origin.

It is a well-known fact that when a normal Zeeman triplet is observed along the lines of force of a magnetic field, the central component is absent, and the two side components are circularly polarized in opposite directions. A quarter-wave plate and Nicol prism mounted over the slit of the spectroscope permit either component to be cut off at will. Furthermore, if the polarizing apparatus be adjusted so as to extinguish one component, reversal of the current through the coils of the magnet will cause this component to reappear, while the other will be extinguished. The method thus offers a simple means of determining the polarity of a magnetic field, which can still be applied when the angle between the line of sight and the lines of force is as great as 60° or 70°. In this case, however, the central line of the triplet is present, and the elliptically polarized light of the side components can be only partially extinguished.

Every sun-spot exhibits a magnetic field, whose polarity is determined by the direction of rotation of the electrons in the spot vortex. To learn the polarity, and hence the direction of rotation, it is therefore only necessary to observe whether the red or the violet component of a spot triplet is transmitted by the polarizing apparatus.

In my earlier work attention was concentrated on a few of the largest spots, in order to secure unquestionable evidence as to the existence of the Zeeman effect. The possibility of finding a law of rotation appeared to be remote, as spots of opposite polarity were observed in the same hemisphere. Subsequently, when the characteristics of bipolar spot groups had been discovered, the search for a rotation law was renewed, with the results given in this paper.

The typical sun-spot group consists of two spots of opposite magnetic polarity, lying on a line which usually makes only a small angle with the solar equator. One of the spots may be replaced by several smaller ones, or even be absent altogether, its place in the latter case being indicated by calcium and hydrogen flocculi. Small companion spots, of either polarity, may attend either member of the pair. The characteristic feature of the group is the presence of magnetic fields, of opposite polarity, in the regions including its eastern and western extremities.

Deferring until another occasion a discussion of the probable origin of bipolar groups, it will suffice for present purposes to emphasize the necessity of recognizing the existence and importance of such pairs. The following quotation from a valuable paper by Father Cortie, based upon a study of some 3500 drawings of spots made at Stonyhurst College Observatory, is of special significance in this connection:

> The chief type, however, of which the above mentioned are in most, possibly in all, cases but phases, is the double spot formation, with a train of smaller spots between the two principal spots of the group, the whole group generally drifting into more or less parallelism with the solar equator. In this form the principal spot, which eventually becomes a normal spot of regular outline, is generally the leading spot, but in many cases it is the following spot, while sometimes the preponderance in area alternates between the two, as the group traverses the disk. In yet rarer instances both the chief spots develop as regular spots. (*Astrophys. J.*, **13.** 261, 1901.)

As the preceding (western) spot of a bipolar group usually lasts longer than the following spot, and is likely to be the larger of the two, we may take it as the dominant member of the group, and classify the polarities of northern and southern spots accordingly. Single spots, followed by a train of flocculi, are classified in Table 1 as preceding spots. Under the headings V and R are given the number of spots for which the "marked strip" of the compound quarter-wave plate transmitted the violet or red component respectively. The spots of the old and new cycles (observed before and after the recent sun-spot minimum) are tabulated separately.

TABLE 1

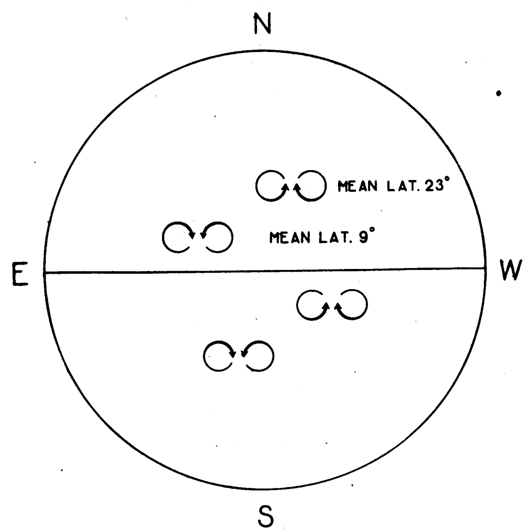
HEMISPHERE	OLD CYCLE				NEW CYCLE			
	Pr. Spots		Foll. Spots		Pr. Spots		Foll. Spots	
	V	R	V	R	V	R	V	R
N	5	0	0	1	0	13	10	0
S	2	16	8	0	9	1	1	7

TABLE 2

	OLD CYCLE		NEW CYCLE	
	N	S	N	S
Mean Φ and No. of spots	10° (7)	9° (22)	22° (11)	26° (6)
Weighted Mean	9.0° (29)		23.2° (17)	

From this summary it appears that the five preceding spots observed in the northern hemisphere before the minimum were characterized by the violet component, while the single following spot gave the red component. In the southern hemisphere, with two exceptions, the polarities were of the opposite sign.

After the minimum, to my surprise, the polarities were found to be reversed in both hemispheres, as the tabulated results for the new cycle indicate. The explanation of this fact probably lies in the change of latitude which a new cycle introduces. While the last spots of the old cycle appear in low latitudes, the first spots of the new cycle occur



much farther from the equator. Thus we apparently have on the sun two spot zones, in which the great majority of spot vortices rotate in opposite directions. The approximate mean latitudes of these zones are shown in Table 2.

From the best supplementary evidence at present available, the true direction of rotation of a preceding spot vortex in the low latitude zone is counter-clockwise, corresponding to that of a terrestrial tornado. The opposite direction obtains in the southern hemisphere, as on the earth. But in high latitudes the signs are reversed—a result which is likely to prove significant in future studies of the sun (see figure). The complete details of this investigation will be published in the *Astrophysical Journal*.