HALE'S ATTEMPTS TO DETERMINE THE SUN’S GENERAL MAGNETIC FIELD

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Abstract. Hale's attempts to determine the sun's general magnetic field are reviewed. The field reported by Hale was an order of magnitude stronger than that presently measured with photoelectric techniques. The polarity was opposite to that expected from Babcock's theory of the solar cycle. Practically all the reduction work had been made by Van Maanen with a tipping-plate micrometer.

To free the reductions from possible personal bias, a few hundred of the plates from the 1914 series were remeasured by the author with the digitized microphotometer at the Sacramento Peak Observatory. The line profiles were recorded on magnetic tape, and the computations of the Zeeman displacements were made using a CD 3600 at Uppsala.

The same plates had been measured visually by Van Maanen. His results show a neat variation of field strength with heliographic latitude, with a maximum of about 11 G at latitudes ± 45°. The solar equator forms a sharp demarcation line between the opposite polarities in the two hemispheres. In contrast, the computer reductions do not reveal any significant field at any latitude. An approximate upper limit for the observed field strength is 5 G. There is no correlation between the new results and the old values by Van Maanen.

1. Historical Background

Observations of solar magnetic fields were started by Hale in 1908 with the 60 foot tower telescope and the 30 foot spectrograph (Hale, 1908a, b and c). Sunspot magnetic fields were measured but attempts were also made to detect a general solar magnetic field. Hale expected the sun to have a dipole-type field, similar to that of a magnetized sphere.

The measurements in 1908 were not accurate enough to reveal these extremely weak fields. It was not until measurements could be made with the newly-constructed 150 foot tower telescope and the 75 foot spectrograph in 1912 that Hale could report successful results (Hale, 1912 and 1913). The observed average longitudinal magnetic field had a maximum strength near heliographic latitudes + and −45°. The sign of the average field was opposite in the two hemispheres, with polarity reversal at the equator. These results were consistent with the hypothesis that the sun's general magnetic field behaved like that of a dipole (Searles, 1913). Hale used this hypothesis to calculate the field strength at the poles. The field strength was found to depend on the spectral line used. There were also systematic differences between different observers. Accordingly, values of the polar field strength between 20 and 50 G were found. The polarity of the field was the same as that of the earth.

Hale reported that every precaution had been taken to eliminate personal bias or other systematic errors. The observers who reduced the plates did not know whether a particular spectrogram had been obtained in the north or south hemisphere or if the compound 1/4 plate had been in the normal or inverted position. The reduction of
the plates obtained in 1912 were made by Miss Lasby and Van Maanen with a comparator and a tipping glass-plate micrometer. Their results agreed in sign although Van Maanen’s values were systematically smaller.

Reductions of the same material by several other observers did not reveal any significant field, but the internal errors were also larger than those by Miss Lasby and Van Maanen. A number of strong lines known to give large Zeeman separations in sunspots failed to reveal any general magnetic field. The conclusions on the strength and polarity of the field were based on the results from four spectral lines which gave significant displacements, and only the reductions by Miss Lasby and Van Maanen were considered to be reliable.

The preliminary results on the existence of a general magnetic field were confirmed by more extensive observations made in 1913 (Hale et al., 1918). A large number of spectral lines were used. 18 of the new lines did not show any measurable displacements caused by a general magnetic field, although they showed a strong splitting in sunspots. 26 other lines were reported to reveal the general field. For these lines the observed average field strength was found to vary strongly with the Rowland intensity of the line. The weaker the line, the stronger was the observed field. This was interpreted as a variation of the field strength with height in the solar atmosphere. Assuming a dipole-type field, Hale found that the polar field strength varied from about zero in the upper photosphere to more than 50 G in the lower photosphere, although the difference in height was less than 200 km. Strangely enough Hale et al. (1918) did not seem to realize that this result was inconsistent with the assumption of a dipole-type field. If the field strength varies so rapidly with height, the field cannot have a large radial component. It must be almost entirely horizontal with the field lines parallel to the solar surface. Hale was of the opinion that the magnetic field determined the structure of the solar corona, but at the same time he accepted the result that the field disappeared above some level in the solar atmosphere. Similar theoretical implications of Hale’s observations were pointed out by Rosseland (1925).

To study the possible influence of personal systematic errors, rather extensive reductions were made by about ten different observers. Half of them confirmed the existence of a general magnetic field, while the other half found no indication of such a field. All the conclusions on the properties of the field made by Hale et al. (1918) were based on the reductions by Van Maanen with the tipping-plate micrometer.

A new series of observations in 1914 made it possible to determine such second-order effects as the inclination \( i \) of the magnetic axis to the rotational axis and the period of rotation \( P \) of the magnetic pole around the axis of rotation. The three Cr I lines \( \lambda \lambda 5247.57, 5300.75 \) and 5329.15 Å were chosen for this purpose. Spectra were photographed daily from June 8 to September 25, 1914. All reductions, involving approximately \( 2 \times 10^5 \) settings with the tipping-plate micrometer, were made by Van Maanen. \( i \) was found to be \( 6°2'\pm0'4 \) and \( P=31.79\pm0.31 \) days. The magnetic pole was on the central meridian at time \( t=\) June 25.31\(\pm0.42 \) (UT), 1914 (Seares et al., 1918).

After some more observational material had been included, revised values for \( i, P \)