THE MAGNETIC FIELD IN THE PROMINENCES OF THE POLAR CROWN

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Abstract. The Hanle effect method has been applied to the determination of the magnetic field in 120 prominences of the polar crown observed during the 1974–1980 period, which is the ascending phase of cycle XXI. The average field strength which was about 6 G at the beginning of the cycle reached twice this value just before the maximum. There is also a clear trend for a increase of the prominence field with the altitude. We confirm the fact that the magnetic vector makes a small angle (25°) with the long axis of the prominence. As to the field orientation, we show that the most striking feature lies in the regular pattern of the component which is parallel to the axis of the filament; its direction seems to depend closely on the polarities of the high latitude photospheric field.

1. Introduction

The prominences of the polar crown are located above the neutral line which separates the polar magnetic region from the medium latitude large scale magnetic cells (McIntosh, 1980). They are well isolated from the active regions; thus perturbations by the active regions are significantly attenuated; this provides an opportunity to observe in these objects a particularly quiet state of the prominence phenomenon, which may be useful as a starting point in the study of the prominence equilibrium.

In this paper we describe recent determinations of magnetic fields wich have been obtained in a homogeneous way before and during the ascending phase (1976–1980) of the present cycle: it is the period of the 'rush to the poles' of the prominences (Waldmeier, 1957) followed by the reversal of polar magnetic fields (Howard, 1972; Howard and LaBonte, 1981).

Our method of measurement has been described in detail in previous papers and is based on the Hanle effect (Sahal-Brechot *et al.*, 1977; Bommier and Sahal-Brechot, 1978; Bommier, 1980). For the magnetic lines of force wich are not far from the horizontal plane – a situation which we have in quiescent prominences (Leroy, 1979) – we are able to derive the strength B of the magnetic field and the angle θ between the magnetic vector and the solar parallel. In the present study we will consider a sample of 120 prominences from both polar crowns; 25% of them have been observed before the 1976 minimum; 5 to 25 independent measurements of the field have been obtained for each prominence with a 5″ angular resolution.

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2. Average Data for the Prominence Field Strength and Direction

2.1. FIELD STRENGTH

Figure 1 shows the average strengths *B* values observed in 120 prominences of both polar crowns in the 1974–1980 period. Although the histogram of *B* is not presented there, it is obvious that the most frequent values lie around 8 G and that *B* remains always in the range 2–20 G. It must be reminded that the longitudinal component of the field measured via the Zeeman effect in the photosphere at the same latitude is of the order of 1 or 2 G. However it is difficult to comment about this difference without any knowledge of the fine structure of the field which is measured in both cases. In the case of the prominences of the polar crown, which are seen edge on, we must also call back to mind that line of sight integration effects are not negligible. The ordinates of Figure 1 are the average heights of our measurements *h* for each prominences; it is approximately half the overall vertical extent of the prominence. For the highest prominences of Figure 1, there may be a tendency to show smaller strengths of the magnetic field: with the help of the pictures which have been always recorded together with the polarimetric measurements we have found that these prominences are the well known curtain-like objects with a fine vertical structure; on the other hand prominences with a stronger field (typically 10–15 G) are often bright and sharp edged.

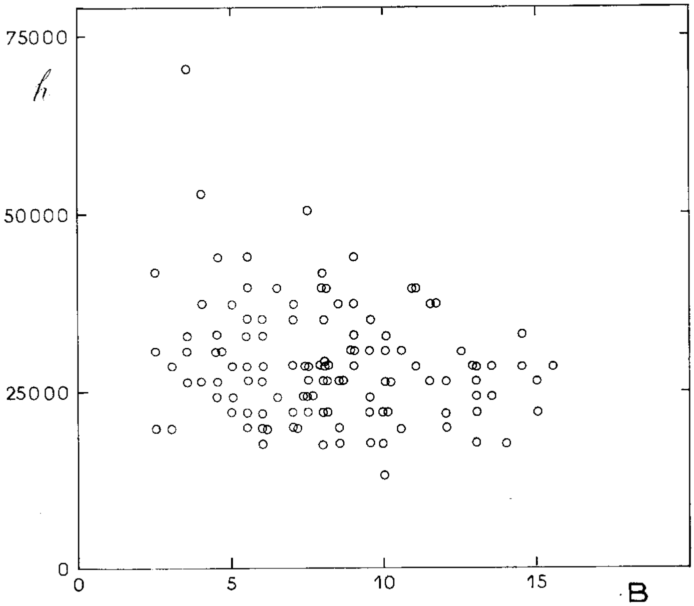

Fig. 1. Ordinates: average height *h* of the measurements performed over a prominence, expressed in kilometers. Abscissas: average field strength *B* measured in this prominence, expressed in gauss.

2.2. INTERNAL VARIATION

It has been known for a long time (Tandberg-Hanssen, 1974) that the strength *B* is quite constant inside the prominence except for a tendency to increase with the altitude (Rust,

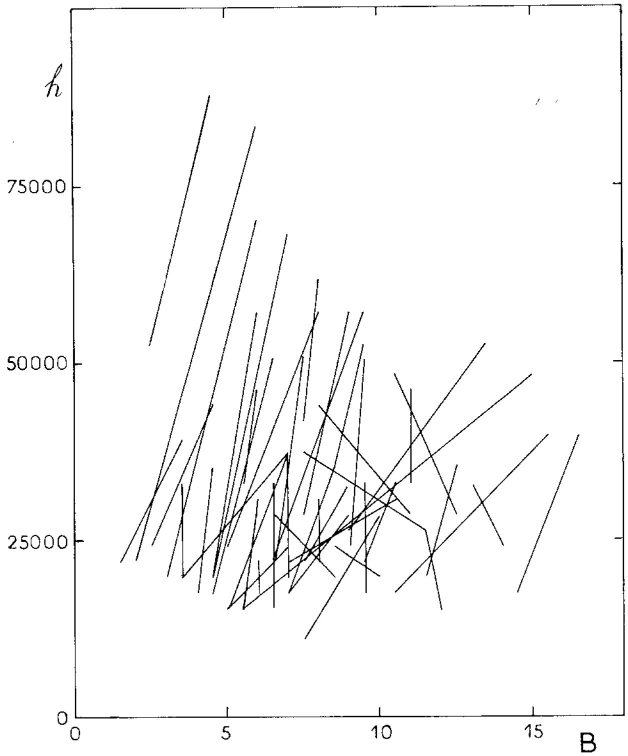

Fig. 2. The coordinates system is the same as for Figure 1; but here the *internal* variation $B(h)$ is given for a selection of well-observed prominences.

1967; Leroy, 1977). We have investigated this effect in 40 prominences of our sample for which a sufficient number of measurements has been performed. The $B(h)$ variations which have been found are reported on Figure 2, and fully confirm the previous results. The most frequent vertical gradient appears to be 0.5×10^{-4} G km^{-1} in agreement with the preliminary result of Rust (10^{-4} G km^{-1}).

2.3. FIELD ORIENTATION

The angular dependence of the field with respect to the prominence long axis and to the neigbouring polarities of the photospheric field appears to be an important parameter for making a choice between different models (Anzer, 1979). Yet there is a difficulty due to the fact that the polarimetric analysis of a line leads to two magnetic vector solutions which are symmetrical with respect to the line of sight. In the case of the polar crown, which is observed edge-on, it is not possible to determine in a straightforward way the direction of the magnetic vector in relation to the adjacent photospheric polarities. There are several indirect methods which allow to choose between the two possible solutions (see for instance Bommier and Sahal-Brechot, 1979) but we shall not describe here this analysis because it is more easily applicable to quiescent prominences which are seen side-on as it will be described in a forthcoming paper.

As to the prominences which are observed exactly edge-on, the polarimetric analysis gives without ambiguity the angle α between the magnetic vector and the long axis of the prominences: this is due to the fact that the two possible solutions are symmetrical with respect to that axis; we obtain thus the histogram of Figure 3a.

As to the prominences which are not observed edge-on the first possible determination of the magnetic vector is consistent with a Kippenhahn–Schlüter configuration: the lines of forces run accross the prominence from the + to the − photospheric polarity. The second determination is consistent with a Kuperus–Raadu model, where the apparent connections between the prominence field and the photospheric field are opposite. If we choose the Kuperus–Raadu configuration we obtain for α the histogram of Figure 3b while the Kippenhahn–Schlüter model leads to the histogram of Figure 3c.

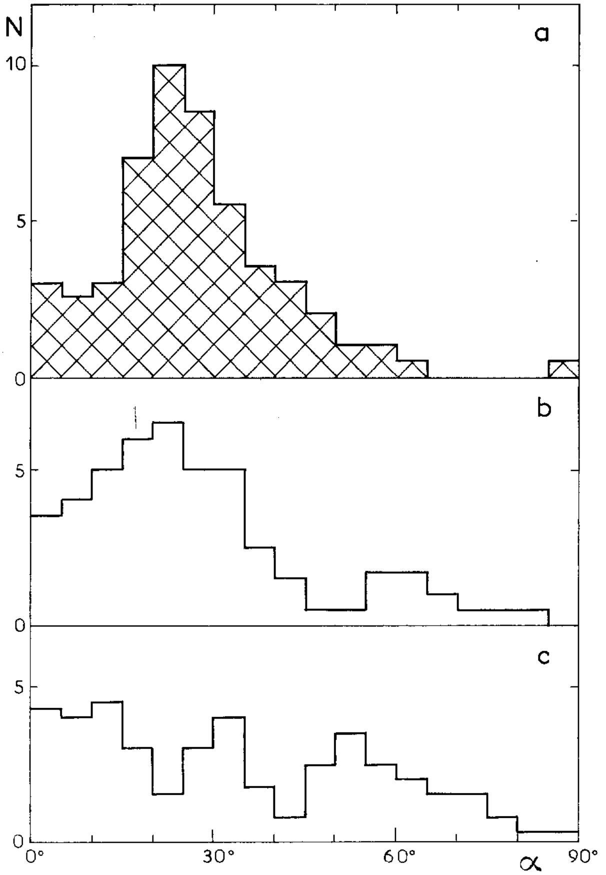

Fig. 3. Number of cases N where an angle α has been observed between the magnetic vector and the prominence long axis. (a) The sample of prominences which have been observed exactly edge on: α can be determined unambiguously. (b) and (c) The sample of prominences which have been not exactly observed edge on: there are two possible determinations of the field vector. If the direction of the field is supposed to be consistent with the Kuperus and Raadu model, one obtains the histogram 3b, whereas for the Kippenhahn and Schlüter model one obtains the histogram 3c.

The fact that the histogram 3b is much closer than 3c from the true histogram which must be that of Figure 3a pleads in favour of a prominence field of the Kuperus–Raadu type, but, indeed, additional confirmations are needed.

This result has been obtained by assuming a homogeneous magnetic field, yet it is clear that unresolved magnetic fine structures may exist and modify the interpretation of the polarization data. A detailed investigation of this question is beyond the scope of this paper and we only mention the fact that our observational results are also consistent with a pattern of helical lines of forces with an horizontal axis parallel to the neutral line and a pitch angle of about 25°. This case and other configurations are currently under study.

3. Cyclic Variation

3.1. D3 LINE INTENSITY

During our 7-years observational period we have observed the well know drift of the polar crown towards the poles, in good agreement with the average behaviour described by Waldmeier (1973), especially in the northern hemisphere.

Although it is not the primary goal of our study our measurements allow to follow the brightness evolution of prominences along the cycle: this may be interesting since very few data are available on this topic in the literature (Gurtovenko and Rachoubovski, 1965).

Our results are displayed on Figure 4 (upper part): the scatter on the intensity $I(\mathrm{D}_3)$ values is real and corresponds to intrinsically different objects: a slight increase of $I(\mathrm{D}_3)$ around the maximum of the cycle is probable.

As it is likely that a part of the scatter of $I(\mathrm{D}_3)$ values is due to an inequal integration length along the prominence body, we have tried to correct as least the cyclic variation of this phenomenon by measuring on the synoptic maps of the chromosphere the probable length involved in each measurement. Then we have derived a corrected intensity $J(\mathrm{D}_3)$ which is the measured intensity $I(\mathrm{D}_3)$ divided by the integration length expressed in units of 50000 km ($J(\mathrm{D}_3)$ would be always equal to $I(\mathrm{D}_3)$ for standard prominences of 50000 km thickness).

It turns out that there is no more cyclic variation in the time evolution of $J(\mathrm{D}_3)$, which confirms our feeling that the apparent variation on Figure 4 (upper part) is probably not characteristic of the variations in the prominence emissivity. Another interesting point is the average value $J(\mathrm{D}_3)$ which is found close to 0.7×10^4 erg cm^{-2} s^{-1} sr^{-1}. By comparing this figure with the recent theoretical model C1 by Heasley and Milkey (1976) we find that $J(\mathrm{D}_3)$ is likely to be emitted by a sum of 5 unresolved prominences threads, each being 1000 km thick. Therefore our result implies a filling ratio of 0.10, which is quite consistent with the recent determination of this quantity (Hirayama, 1979).

3.2. FIELD STRENGTH

The lower part of Figure 4 displays the time variation of the magnetic field strength B in prominences of both polar crowns: the three star points correspond to measurements

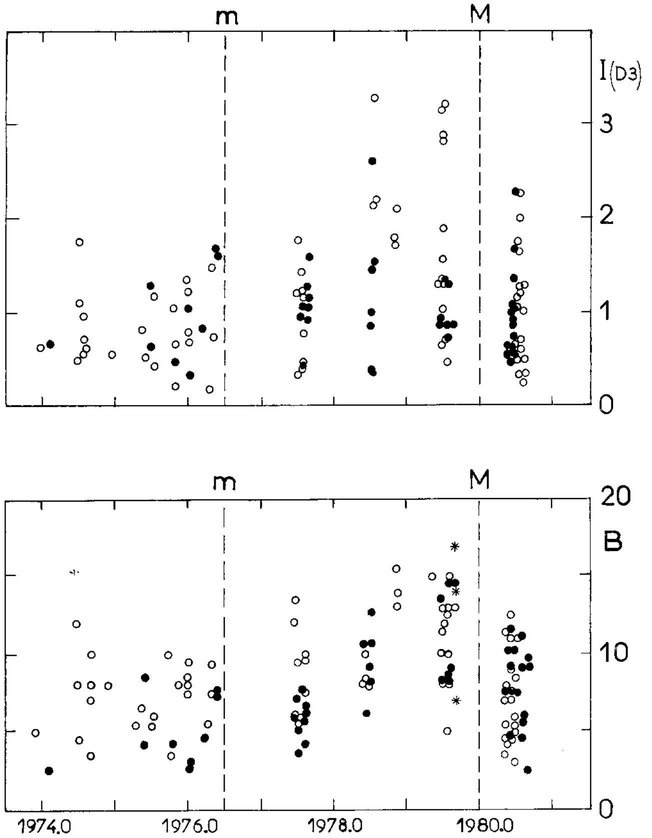

Fig. 4. Abscissas: years and epochs of the beginning and maximum of cycle XXI. Ordinates: upper diagram, the intensity $I(D_3)$ of the D_3 line expressed in units of 10^4 ergs cm^2 s^{-1} sr^{-1}; lower diagram, the average field strength B in gauss. White circles refer to observations in the northern polar crown and black circles to those of the southern crown. The three star-points in the lower diagram correspond to measurements by Nikolsky *et al.* (1982).

of $B_{\parallel}$ by Nikolsky *et al.* (1982) with the help of a method based upon the Zeeman effect: it is obvious that $B_{\parallel}$ and B should be approximately equal, owing to the geometrical conditions of obsevations of the polar crown: thus it is interesting to notice the good agreement between the magnetic field measurements deduced from the Hanle effect and those deduced from the Zeeman effect with quite different interpretation methods.

Another evidence of this agreement is given by former measurements made at Climax, 1 cycle earlier (Tandberg-Hanssen and Anzer, 1979): B was about 9 ± 6 G, which fits well with our result for 1980, at the same phase of the solar cycle.

For a given phase of the cycle the standard deviation on our determination of B is about ± 3 G. Therefore average values deduced from at least 10 prominences have a standard deviation of less than 1 G and it is most likely that the variation of B between 1976 and 1980 is real.

3.3. FIELD ORIENTATION

We want finally to comment about the cyclic variation of the magnetic vector direction in the polar crown. It has been known since the measurements of Rust (1967) that the pattern we have observed for the 1974–1980 period was indeed reversed 10 years earlier and we have already mentioned (Leroy, 1978) that former Lyot measurements also displayed the same periodic variation. Now, we can also find on high latitude prominences an indication of the cyclic variation of the field direction: Figure 5 shows a schematic view of the filaments present on the Sun on July 15, 1980 with an emphasis given to high latitude prominences. We have indicated there the polarities of the photospheric field and the direction of the main component of the prominence field which is the component along the filament: the reversal of the field direction along the neutral lines has been already visible at latitude ± 45° one year before the disappearance of the old polar crown.

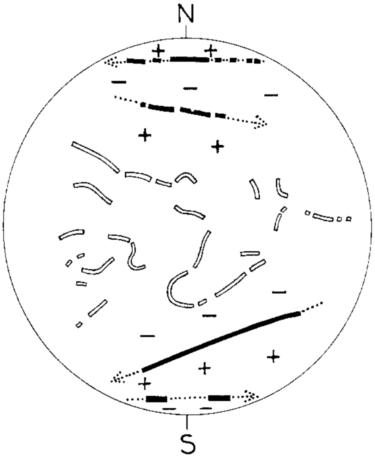

Fig. 5. A schematic view of prominences observed on the Sun on July 15, 1980 with emphasis on high latitude filaments. Dotted arrows show the orientation of the field vector measured in prominences, + and – refer to the polarities of the photospheric magnetic field.

4. Conclusion

This paper summarizes the properties of the magnetic field of the prominences of the polar crown which are observed during the ascending phase of cycle XXI, namely:

- average magnetic field strength around 8 G;
- field strength vertical gradient of 0.5×10^{-4} G km^{-1};
- average angle of 25° between the magnetic vector and the filament long axis;
- no clear cyclic variation of helium emissivity;
- average emissivity consistent with a filling ratio of 0.10;
- maximum field strength just before the cycle maximum;
- cyclic reversal of the field direction along the neutral line.

Though the weakness of these results comes from the fact that we provide 'average' results for prominences which look very inhomogeneous, we believe that it is useful to have a consistent set of data for a well defined family of prominences which represent probably the quietest state of the prominence phenomenon.

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