LETTERS TO THE EDITORS

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The Sun's General Magnetic Field

SOME of the recent theoretical discussions of the magnetic field of the Sun have tended to throw the subject into a state of confusion[1-3]. In particular, H. Alfvén[3] asserts that "... it is at present impossible to derive a value of the sun's general magnetic field from spectroscopic measurements", and that "quite without justification it is assumed that Zeeman-effect measurements give an accurate value of the solar magnetic field".

Such a statement is in conflict with the published observations of weak solar magnetic fields, and of the discussion that has been given to these observations[4].

Alfvén begins with the not unreasonable assumption that in the turbulent photosphere there is equipartition of energy between the kinetic and the magnetic modes. He argues that the intensity of the spectral line in which the Zeeman effect is measured is a function, f, of density, ρ, and temperature, T, and that in the granules ρ, T and the magnetic field H are coupled, so that "it is not at all likely that the average Zeeman effect gives an average of the magnetic field". Alfvén assumes (apparently on the basis of a particular theory of the origin of sunspots) that there is a general field H_0 of the order of 10 gauss. This is superimposed on the turbulent field H_t, so that in some parts of a granule the resulting field is $H_0 + H_t = + 10 + 300 = + 310$ gauss, whereas in other parts of it the field is $H_0 - H_t = + 10 - 300 = - 290$ gauss. The average then depends on the function $f(\rho, T)$ and the way in which ρ and T are coupled with H. If f is systematically smaller for positive values of H_t than for negative values, "the measured H_m may very well be negative even if the real field H is positive, and its absolute value may differ by orders of magnitude". Hence, according to Alfvén, "no conclusion can be drawn about the general magnetic field from the Zeeman-effect measurements and the results of these measurements are not relevant".

I believe that Alfvén greatly over-estimates the importance of the possible coupling of H with line intensity, and that his conclusion may readily be refuted by consideration of the published observations.

According to Alfvén's argument, the systematic effect of f and the way in which ρ and T are coupled with H should provide a large bias (probably subject to a centre-to-limb effect) underlying the much smaller true field. But the measurements of the Zeeman effect are absolute, and they show no trace of bias. Vast areas of the Sun, and occasionally, near sunspot minimum, the greater part of the solar disk, show no observable field distinguishable from zero. The limit is about 0·5 gauss for the 'noise' peaks, and much lower for any possible bias.

A further very significant result that was brought out in the discussion of the extensive series of observations with the solar magnetograph concerns the measured magnetic fields of bipolar magnetic (BM) regions, which exhibit a vast range of total magnetic flux. The large bipolar magnetic regions, while young, characteristically contain leading and following sunspots of opposite polarity. For such spots, G. E. Hale[5] established the well-known laws of magnetic polarity that pertain to the N- and S-solar hemispheres and to the alternation in successive 11-year sunspot cycles. As we have indicated, well-defined bipolar magnetic regions have approximate equality of positive and negative flux in the respective parts; the observations substantiate the concept of a localized loop of a submerged toroidal field rising above the surface, as suggested by Cowling[6]. Now in the N- or S-hemisphere of the Sun, in a given sunspot cycle, the same relative polarity of leading and following parts of all well-defined bipolar magnetic regions is exhibited over the whole range of magnetic intensity, from the very strong, spotted bipolar magnetic regions ($H \approx 3,000$ gauss) down to those (unspotted) of minimal size having average field intensities of only one or two gauss. Furthermore, weak bipolar and unipolar magnetic (UM) regions are frequently identifiable and measurable for days or weeks as they are carried across the disk by the solar rotation, even though they may be surrounded by vast areas having no outstanding field.

This disposes completely of the idea that the turbulent field of the granules systematically reverses, or appreciably biases, the measured Zeeman effects of weak magnetic regions on the Sun.

If, then, the polarity and approximate magnetic intensity of weak bipolar magnetic regions can be reliably observed, there is no reason for doubting the observations of weak fields, consistently positive near the north pole, negative near the south pole, that constitute the 'general' magnetic field of the Sun. After correction for darkening at the limb and for the presumed projection factor, the average intensity of the general field near the poles has been stated to be of the order of one gauss[4]. This is an order of magnitude weaker than the field required by Alfvén's theory of sunspots, and as Alfvén states, his solar model "seems to be in striking conflict with the Zeeman-effect measurements if these are interpreted in the naïve way as really measuring an average field". Since there is as yet no generally accepted theory of the magneto-hydrodynamic effects in solar granules, and since it would appear that such a theory, when finally perfected, will probably lead to rather minor refinements of the measured field intensities when averaged over large regions, we may have to continue with the present interpretation of the observations.

It may be mentioned that a second solar magnetograph[7], incorporating certain technical improvements and operating with the advantage of the better sky of Mount Wilson as compared to Pasadena, confirms the existence and polarity of the weak polar fields of the Sun previously reported.

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