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6. THE SMALL SCALE STRUCTURE OF SOLAR MAGNETIC FIELDS

OBSERVATIONS OF SMALL-SCALE PHOTOSPHERIC MAGNETIC FIELDS

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1. INTRODUCTION

If the Sun is observed like a star, without spatial resolution, its magnetic field seldom exceeds 1 Gauss. But with high spatial resolution the field is seen to be largely concentrated into kG structures. Observations of the structure and dynamics of solar magnetic fields can therefore provide a guide to the nature of magnetic fields of other stars which cannot be resolved. Solar activity and the structure of the chromosphere and inner corona are intimately linked with magnetism and a complete understanding of these features often depends on magnetic field details. There are unsolved physical problems involving solar magnetic fields which have challenged many physicists. For example, confinement of small-scale fields in kG structures is a problem of current interest (Parker, 1976; Piddington, 1976; Spruit, 1976). Solar observers are no less challenged since the Sun presents us with a complicated magnetic field having a range of scales from global to less than the scale of our best observations as illustrated in Figures 1, 2, and 3. This paper is a survey of observational techniques and results at the small-scale end of the spectrum of sizes in the solar photosphere. This topic has been frequently reviewed (e.g. Athay, 1976; Beckers, 1976; Deubner, 1975; Howard, 1972; Mullan, 1974; Severny, 1972; Stenflo, 1975) so that recent work is emphasized here.

Many techniques are available with which to observe or infer solar magnetic field properties ranging from direct *in situ* measurements such as those made by the *Helios* spacecraft to purely theoretical inferences. Discussions of these techniques have been published recently (Beckers, 1971, 1976; Schröter, 1973; Staude, 1974; Vrabec, 1974). This survey is limited to observations which depend directly or indirectly on the Zeeman effect in photospheric spectrum lines since this is the most powerful technique presently available. Stenflo (1971) reviewed how solar spectrum lines are altered by the Zeeman effect. The observations

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are not easy to interpret because we cannot resolve the small-scale inhomogenieties directly and properties must be inferred by relying more or less on models. This procedure is laden with traps for the unwary and the emphasis here is on the observational results rather than the models used to interpret them.

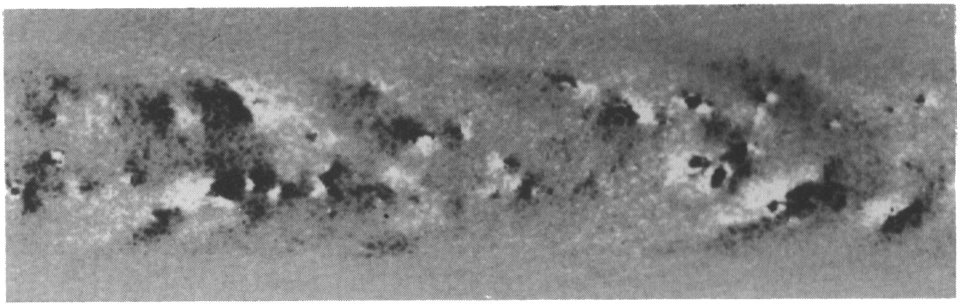

Figure 1. A synoptic map of measurements of the line-of-sight component of the photospheric magnetic field covering one solar rotation in March 1970. North is at the top and east is to the left. (KPNO magnetogram)

In reference to Figures 1, 2, and 3 it is convenient to consider the small-scale part of the complicated pattern as composed of a) sunspot fields, b) active region fields, c) network fields, and d) inner network fields. Sunspots deserve a separate discussion such as that presented by Beckers (1975) and are not discussed further here. Outside

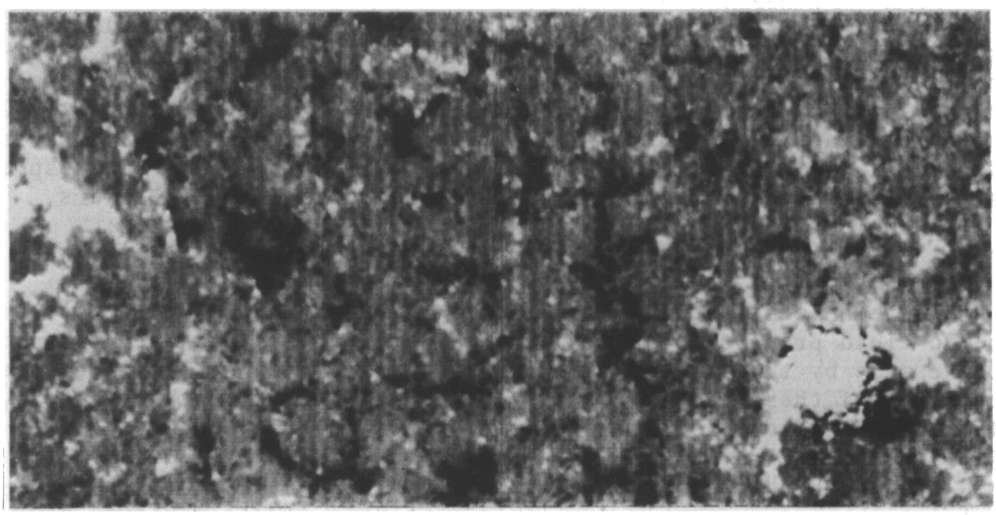

Figure 2. Line-of-sight component of the quiet photospheric magnetic field near the disk center on 9 September 1974. An old sunspot is at the lower right and strong field concentrations can be seen in a network pattern. Small inner network fields are found all over the area of 200" x 400". (KPNO magnetogram)

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of sunspots, the magnetic field appears to be organized into elements with remarkably similar properties; the main distinction between active region fields and network fields is apparently the number of 'basic' elements per unit area. In areas with a large number of elements there is a tendency for the elements to cluster together to form larger cohesive structures so that a spectrum of size scales is observed, but even in large active regions the 'basic' small-scale structure is clearly identifiable. For that reason we treat the small-scale structure of active region and network fields as basically identical. Little is known about inner network fields but they appear qualitatively different from the network fields. The following discussion divides observational results according to whether one or more spectrum lines were used. Within each section the most direct results are discussed first.

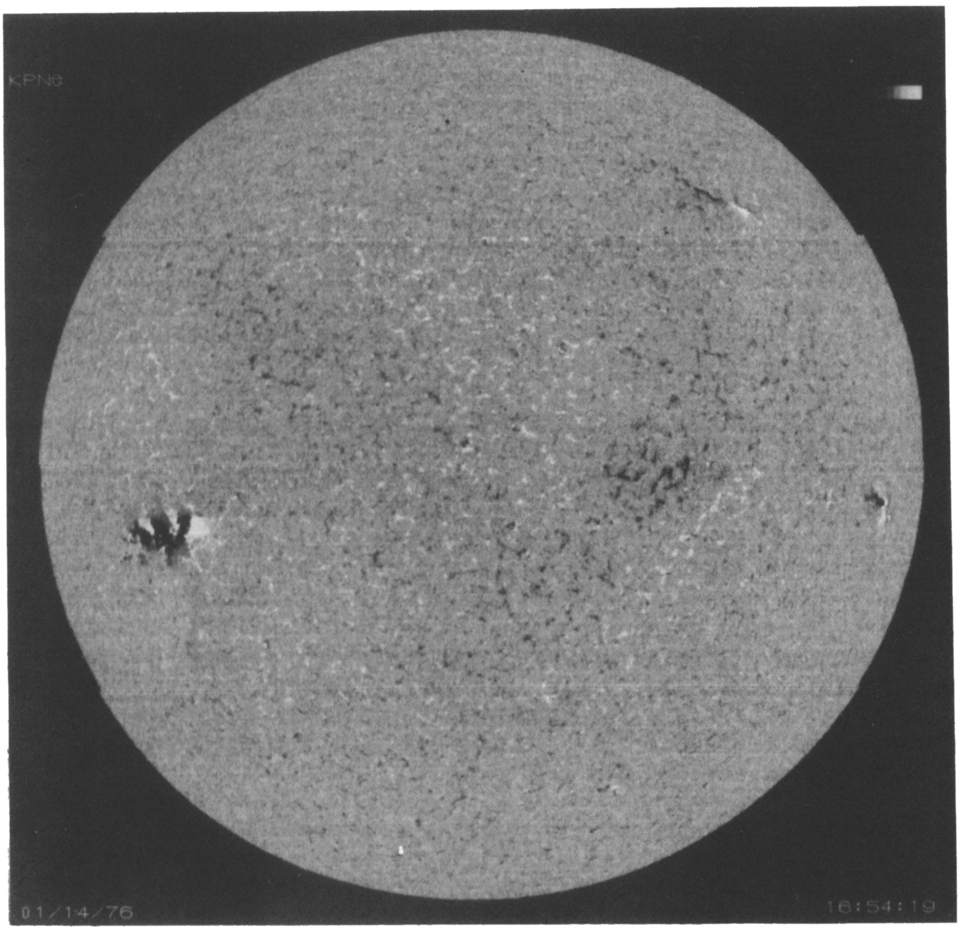

Figure 3. Line-of-sight component of the photospheric magnetic field on 14 January 1976. Faint remnants of old active regions form a large pattern near disk center while young active regions are seen near the equator in the south and a new cycle active region is located in the northwest. (KPNO magnetogram)

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2. OBSERVATIONS WITH SINGLE SPECTRAL LINES

2.1 Direct observations of line profiles

When Zeeman splitting is small relative to observed line widths, the Zeeman effect introduces broadening, line profile changes, and (usually) changes in line equivalent width in unpolarized light. Measurement of these quantities offers the possibility of learning the average magnetic field strength (weighted as mentioned below) in volumes which include network and non-network regions. The problem with this technique is that many other mechanisms in addition to the Zeeman effect can cause line broadening and changes in line profile and equivalent width.

The Zeeman effect introduces polarization in line profiles and few, if any, other mechanisms can be imagined which cause closely similar polarization effects. Thus, most measurements of non-sunspot magnetic fields have made use of the polarization properties of the Zeeman effect. The outer (σ) components become oppositely circularly polarized in a field along the line of sight. If the Zeeman splitting is large then the difference between two opposite circularly polarized spectra clearly reveals the σ components and a measure of their separation yields the average of the line-of-sight component of the magnetic field in the observed volume weighted by any variation of the relative strength of the spectrum line as a function of line-of-sight field strength. Systematic velocity fields associated with the magnetic field will shift both the σ components relative to the position of the unpolarized spectrum line and velocity gradients will cause asymmetric σ components. In the visible spectrum the Zeeman splitting in non-sunspot field is not large enough to directly detect the σ components. By using an infrared line at 15648 Å which exhibits about 3 times the Zeeman splitting of visible lines, Harvey and Hall (1975) were able to resolve the σ components in circularly polarized spectra in non-sunspot fields (Figure 4). Splittings corresponding to average line-of-sight field strengths *in the magnetic elements*, $\langle B_\ell \rangle$, between 1200 and 1700 G were measured; peak field strengths in excess of 2 kG were not excluded by the observations. A systematic red shift of the σ components corresponding to 2.2 ± 0.7 km s^{-1} was observed. The weakness of the σ components suggested that the magnetic elements filled less than 10% of the resolution element ($\sim 2''$) unless the spectrum line systematically weakens in the magnetic field region.

In the visible spectrum the σ components are blended with the unpolarized spectrum line and with each other and a less direct technique is required to extract average field strengths within the magnetic elements. Seares (1913) derived simple expressions for line profiles expected in polarized and unpolarized light which are valid in the case of a homogeneous field and optically thin lines. He further showed that in the case of small Zeeman splitting the wavelength displacement of the line center or center of gravity of the circularly polarized line profile is proportional to the line-of-sight component of the field.

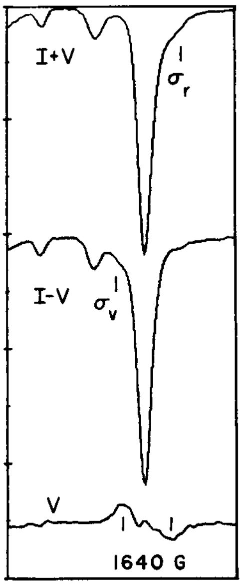

Figure 4. The 15648 Å line observed in opposite circular polarizations in a network field element. The difference spectrum at the bottom shows separation of the σ components corresponding to a mean line-of-sight field strength of 1640 G. (Harvey and Hall, 1975)

These results have been used to interpret observations even when the Zeeman splitting is not small and the spectrum line is not optically thin. Semel (1971) showed that the displacement of the center of gravity of circularly polarized line profiles is not very sensitive to violations of the Seares assumptions. Thus, the Seares results can be used to interpret observations of moderately strong spectrum lines and Zeeman splitting to yield estimates of the strength of the line-of-sight component of the field *averaged over the resolution element* and weighted by correlated changes of line strength with field strength. The symbol (B_ℓ) will be used below to denote this quantity. Values of (B_ℓ) are sensitive to spatial resolution and have steadily increased with improved observations. Sheeley (1967) found values of (B_ℓ) of 350 G. Steshenko (1967) reported values ranging up to 1400 G based on visual measurements which can take advantage of the best moments of seeing. The most recent study of this sort (Simon and Zirker, 1974) achieved a spatial resolution not likely to be soon exceeded with ground-based observations and they reported 100 G $< (B_\ell) <$ 1500 G. They also found a good association between magnetic regions and relative downward motion. They believe their observations resolve the magnetic structures and find sizes > $1''.5$ but it is possible that they resolved only clumps of smaller elements and not the smallest elements themselves.

Title and Andelin (1971) initially employed the same technique above and found 100 G $< (B_\ell) <$ 500 G. Tarbell and Title (1975) reanalyzed the data using a Fourier transform technique (Title and Tarbell, 1975) to extract $\langle B_\ell \rangle$ values typically around 1500 G in regions 2-3" in size with one case of 1950 G reported. Numerical experiments by Heasley (1976) suggest that the Fourier transform method of extracting $\langle B_\ell \rangle$ values is not always reliable so results must be treated with caution until this new method is more fully developed.

Beckers and Schröter (1968) investigated network fields (which they called magnetic knots) using circularly polarized spectra and deduced values of (B_ℓ) in the range 250-400 G for structures 2-3" in size. They proceeded beyond earlier investigations by using the Unno (1956) theory for the formation of spectrum lines in magnetic fields to match their observed profiles. After correction for dilution of the observed spectrum by stray light from non-magnetic regions they inferred values 600 G < $\langle B_\ell \rangle$ < 1400 G in regions with sizes of about 1"3. They also reported a tendency for the magnetic structures to be associated with relative downward motion and dark intergranular regions.

2.2 Indirect determinations of line profiles

Spectroheliograms and filtergrams with good spectral resolution taken in circularly-polarized light with different parts of the profile of a Zeeman-sensitive spectrum line can be used to infer the profile of the σ components in magnetic regions relative to the mean line profile in non-magnetic regions. Using this technique, Giovanelli and Ramsay (1971), Sheeley (1971) and Schoolman and Ramsey (1976) all report a redward systematic displacement of the σ components corresponding to a downflow of about 0.5 km s^{-1}. This value should be independent of spatial resolution and represents a weighted mean value in the magnetic region in a volume where the core of the 6103 Å CaI line is formed. Unfortunately, determination of the amount of splitting of the σ components by measurement of the amount of polarization of the magnetic elements in the line wings is resolution dependent and only values of (B_ℓ) can be estimated.

2.3 Measurements in line wings

The Seares expressions provide a foundation for determinations of (B_ℓ) by measurement of the shift of the center-of-gravity of oppositely circularly polarized spectra. The magnitude of the shift can be inferred from the intensity difference between the opposite circular polarizations measured in the wing of a suitably selected spectrum line. This is the principle of operation of most solar magnetographs. Unfortunately calibration of this technique requires the assumption that the line profile in the magnetic region is unchanged in shape, strength and average wavelength compared with surrounding non-magnetic regions. Although these requirements are generally violated the procedure outlined is widely used to interpret longitudinal magnetograph observations. This violation leads to the expectation that most such determinations of (B_ℓ) are underestimates of true values. Photographic (Sheeley, 1966) and photoelectric (Livingston and Harvey, unpublished) observations with spatial resolution approaching 1" typically yield (B_ℓ) values of a few hundred Gauss with peaks of 700-800 G in network fields. Lynch (1974) expressed his measurements of network field clumps near the disk center in terms of net flux and found typical values of 2 x 10^{19} Mx.

Magnetograph observations in the best seeing conditions with high sensitivity (Figure 2) reveal inner network magnetic fields (Livingston and Harvey, 1975). The inner network fields exhibit a granular pattern of mixed polarities with a scale of about 2" and net flux values within resolved elements of about 5 x 10^{16} Mx. Inner network fields are transient with a time scale of the order of 30 min as shown by 2 frames from a movie in Figure 5. Smithson (1975) also detected inner network fields and suggested that the true field strength in these features is

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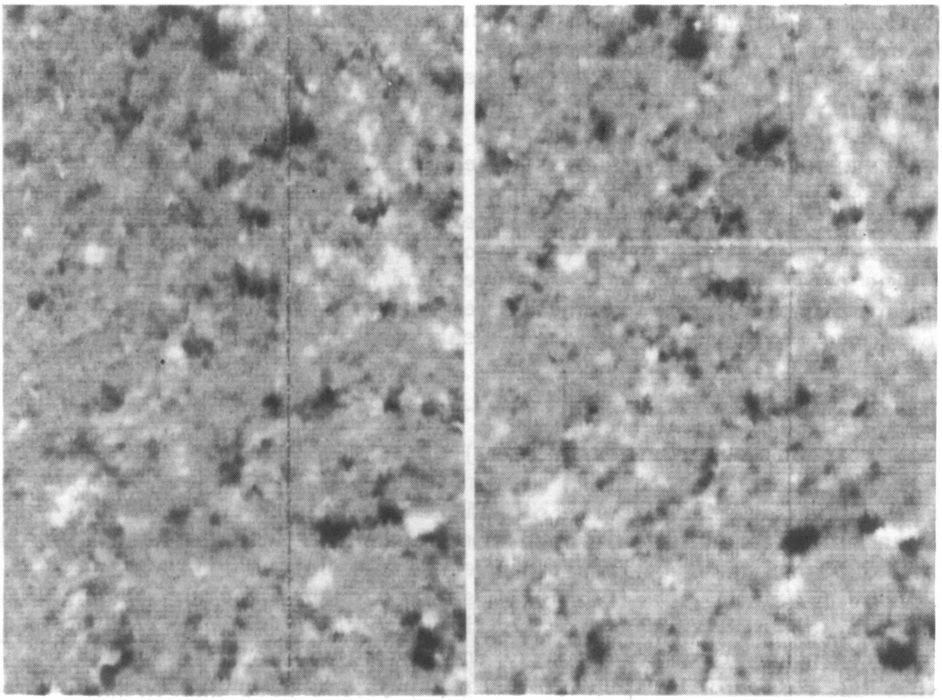
less than in network fields. The small-scale mixing of opposite polarities in the inner network fields makes their detection very sensitive to spatial resolution. A similar dependence of measured (B_ℓ) values in network fields on spatial resolution was found by Stenflo (1966).



$\Delta T = 70$ min

Figure 5. Two frames from a movie of the quiet magnetic field near disk center showing time changes in the network and inner network field in a period of 70 min. (Livingston and Harvey, 1975)

3. OBSERVATIONS WITH MULTIPLE SPECTRAL LINES

As noted above, single spectral lines are affected by so many variables in addition to the magnetic field that observations are often difficult to interpret. An old solution to this problem is to use sets of spectrum lines selected to emphasize sensitivity to some desirable parameter and suppress sensitivity to other variables. This approach has been widely used in magnetic field studies and is quite powerful. One danger of this seductive approach is a tendency to forget that observations are spatial averages which can effectively hide some kinds of fine structure even from powerful line ratio techniques.

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3.1 Line profile effects

Unno (1959) used pairs of lines from selected multiplets in an attempt to determine if a systematic broadening with increasing Zeeman sensitivity could be detected. No positive results were obtained and an upper limit of 300 G for the average field strength was established. Howard and Bhatnagar (1969) found a difference of 20 ± 15 G between the magnetic field strength of granular and intergranular regions from the correlation of line width differences with Zeeman sensitivity on a high quality spectrogram. This value, however, depends on how well the intergranular lanes were resolved and this is not known.

Chapman and Sheeley (1968) studied the variation of the central intensities of several spectral lines as functions of Zeeman and temperature sensitivity and concluded both effects produced line weakenings in network elements. Chapman (1976) observed changes in several complete line profiles in network features and matched the profiles with a model atmosphere having magnetic elements with values of $\langle B \rangle$ of about 1620 G at the level of formation of weak spectrum lines.

3.2 Use of one line as a reference

Simultaneous observations of (B_ℓ) using two spectrum lines were pioneered by Soviet astronomers (e.g. Severny, 1966). These observations were interpreted in terms of height variations of the field. Harvey and Livingston (1969) found simultaneous observations of (B_ℓ) with the 5250 and 5233 Å lines to give a large but nearly constant discrepancy (Figure 6). Following a suggestion by Chapman and Sheeley (1968), they assumed that a high sensitivity of the 5250 Å line to temperature and a presumed increase in temperature in network field elements was responsible for the discrepancy. But interpretation of discrepancies simply in terms of height or temperature effects alone is incorrect. As Stenflo (1968) pointed out, there are many potential sources of discrepancies in (B_ℓ) measurements and all potential sources must be observationally proven to be unimportant for a particular spectrum line before any single source can be safely ignored.

Using the same magnetograph, Frazier (1970) confirmed the observational results of Harvey and Livingston (1969) and further showed that velocity measurements made with the 5233 and 5250 Å lines also show a discrepancy in network field elements in the sense that the 5233 Å line showed a systematic downdraft but the 5250 Å line did not. Frazier (1974) later proposed that the velocity discrepancy was due to large Zeeman splitting of the 5250 Å line in network elements which caused a loss of sensitivity to network velocities (Zeeman saturation). The field strengths required fell in the range 1300-2600 G depending on model assumptions.

Howard and Stenflo (1972) used a different instrument and non-simultaneous observations and found that the discrepancy between measures of (B_ℓ) with the 5233 and 5250 Å lines decreased at low values of (B_ℓ).

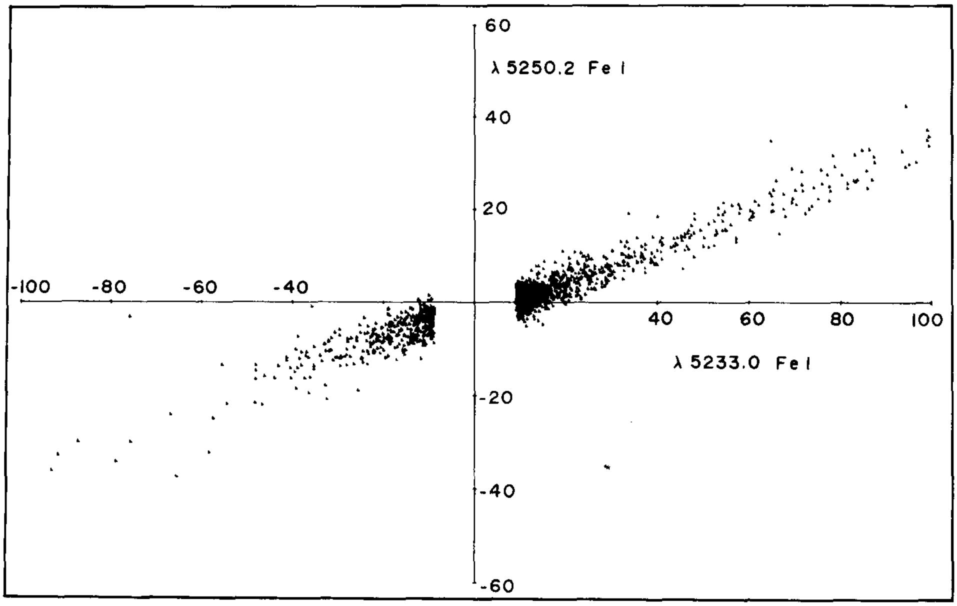

Figure 6. Simultaneous measurements of (B_ℓ) in Gauss with the 5233 and 5250 Å spectrum lines. A systematic discrepancy is obvious. (Harvey and Livingston, 1969)

This was interpreted as due to time changes in the pattern of field distribution with a scale of hours. Using a model proposed by Stenflo (1971), the observed discrepancy was interpreted as due to a systematic reduction of the 5250 Å line signal in magnetic elements with large field strength. This model allowed an estimate to be made that with a resolution of 17" more than 90% of the flux observed with the 5233 Å line was subject to the discrepancy. They also discovered that the discrepancy shows a significant center-to-limb variation (Figure 7) which was interpreted as due to a rapid decrease of field strength with increasing height.

Further studies of the 5250-5233 Å discrepancy by Frazier and Stenflo (1972) used higher spatial resolution observations taken mainly in active regions. The center-to-limb variation was confirmed and it was found that a for positive values of $(B_\ell)_{5233}$ there was a negative bias in $(B_\ell)_{5250}$ of a few Gauss (and *vice versa* for negative values of $(B_\ell)_{5233}$). The effect may be seen in Figure 6. Using a two-component model this effect was explained as due to weak, opposite polarity fields systematically associated with the strong network elements. The bias has not been confirmed in other observations and we now suspect a computer program error affecting Kitt Peak observations in 1968 and 1969 is the cause of the bias.

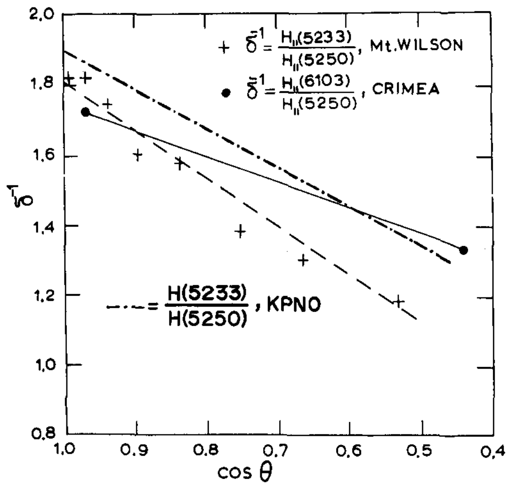

Figure 7. Center-to-limb variation of mean discrepancies in measures of (B_ℓ) with pairs of spectrum lines at the Mt. Wilson (dashed), the Crimean (solid) and the Kitt Peak (dash-dot) observatories. (Howard and Stenflo, 1972; Frazier and Stenflo, 1972; Gopasyuk *et al.*, 1973)

Gopasyuk *et al.* (1973) studied observations made with the Crimean Observatory double magnetograph using many different pairs of spectrum lines. They found intrinsic scatter in values of the discrepancy made with a given pair of lines at a specific disk position. They confirmed the center-to-limb variation (Figure 7) and showed that the average value of the discrepancy is a strong function of the Zeeman sensitivity of the spectrum lines involved (Figure 8) in the sense that larger values of (B_ℓ) were observed with less Zeeman-sensitive spectrum lines.

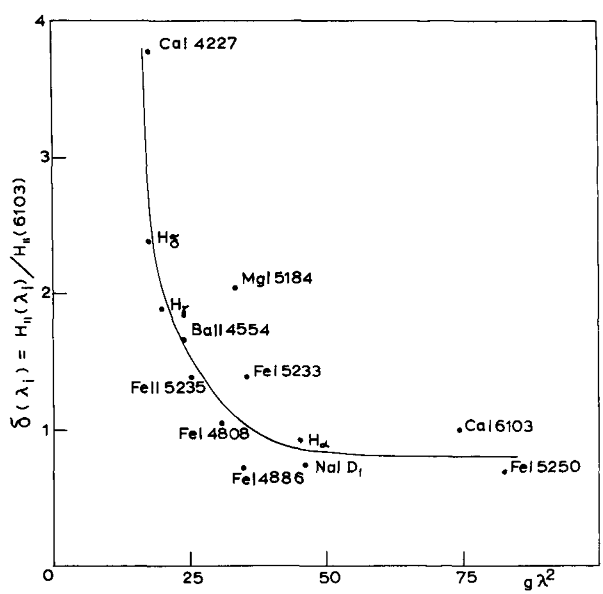

Figure 8. Variation of mean discrepancies in (B_ℓ) measurements with different pairs of spectrum lines as a function of Zeeman sensitivity. (Gopasyuk *et al.*, 1973)

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In an unpublished study, Harvey (1972) used higher sensitivity than had previously been available to confirm that values of $(B_\ell)_{5233}/(B_\ell)_{5250}$ show larger scatter at given values of $(B_\ell)_{5233}$ than instrumental sources can explain (Figure 9). On the other hand, it was found that the number distribution of $(B_\ell)_{5233}$, corrected for noise, could be fit very well by a sum of the $(B_\ell)_{5250}$ distribution plus the $(B_\ell)_{5250}$ distribution scaled and widened by a constant to get the best fit. This confirmed that about 93% of the magnetic flux measured with the 5233 Å line is subject to some effect causing a discrepancy in (B_ℓ) measurements with the 5250 Å line at a spatial resolution of about 3".

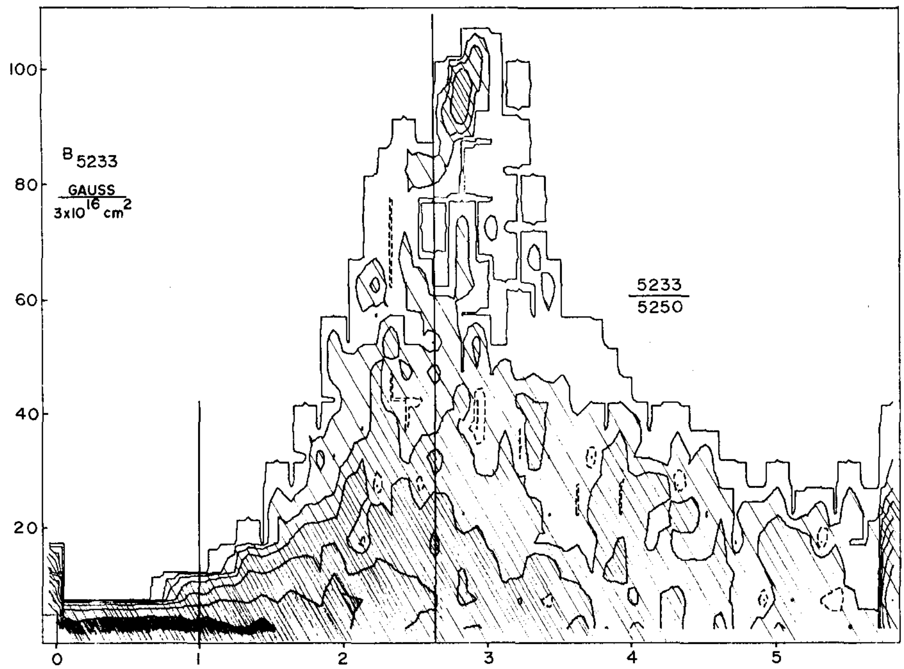

Figure 9. Isopleths increasing by factors of 2 showing a range of values of the ratio of $(B_\ell)_{5233}/(B_\ell)_{5250}$ at given values of $(B_\ell)_{5233}$. At large values of $(B_\ell)_{5233}$ a mean discrepancy of 2.6 is found but this approaches 1 as $(B_\ell)_{5233}$ decreases. Values of $(B_\ell)_{5233} > 80$ G are instrumentally saturated. (KPNO observations)

Livingston *et al.* (unpublished) are critically examining the nature of (B_ℓ) discrepancies using several pairs of lines. One of their results has considerable significance because none of the proposed sources of errors in (B_ℓ) measurements predicts that the 5233 Å and similar lines should give large errors. Using the 5253 Å line as a reference, Livingston measured (B_ℓ) using different parts of the 5233 Å line and found a variation of more than a factor of two in the sense that larger values of (B_ℓ) are measured near the core of the 5233 Å line than in its wings. The same behavior is observed in the 8688 Å

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line. An explanation of this curious effect is not obvious but the direct implication is that the line profile weakens considerably more in the wings than in the core in network field elements. This might be due simply to temperature increases in the network or to a decrease in optical depth within the magnetic field element relative to the surroundings with increasing geometric depth. Livingston suggests that the heating hypothesis is only likely to be consistent with observations of line profile changes in faculae (Stellmacher and Wiehr, 1971) if the heated area is too small to be resolved in facular line profile observations at low heights. An optically-thin magnetic structure at low height implies a depressed tube-like structure similar to sunspots (without darkening) and one might expect a strong variation of observable parameters as a function of distance from disk center in vertical tubes. In fact, another of Livingston's observations is a strong variation of the (B_ℓ) discrepancy in the range $1.0 > \mu > 0.95$ using several different line pairs. Further, the ratios of (B_ℓ) values measured with different parts of the 5233 Å line vary most at $\mu \simeq 1.0$ and show considerably less variation at values of $\mu \leq 0.8$. Observations with the 8688 Å line yield similar results.

3.3 Use of two lines of the same multiplet

In order to reduce the effects of all variables except magnetic field from (B_ℓ) observations, Stenflo (1973) made simultaneous observations using two lines nearly identical in every aspect except Zeeman sensitivity. Observations at the same place in the line wings should give identical values of (B_ℓ) unless one line suffers more Zeeman saturation than the other. Stenflo observed the ratio of the values of (B_ℓ), which he called k, to vary with distance from line center and to approach a value of 1 only in the extreme wings. Stenflo interpreted his observations using a two-component model and various vertical field strength profiles together with the Unno (1956) theory. Values of damping and Doppler broadening were assumed and the line strength, field strength, and relative velocity within the magnetic region were left as free parameters. Line strength and velocities less than 1.2 km s^{-1} were found to have little effect on k. Doppler shifts larger than 1.9 km s^{-1} could be excluded. Only Zeeman splitting had a significant effect on k. Depending on the choice of field strength profile, peak values of B_ℓ ranging between 1670 and 2300 G and mean values $\langle B_\ell \rangle$ between 620 and 835 G best fit the observed values of k. A model having a homogeneous magnetic field component and a non-magnetic component gives a value of $\langle B_\ell \rangle = 1100$ G (Stenflo, 1975). A mean downdraft velocity of about 0.5 km s^{-1} could be inferred from the observations. Assuming a flux of 2.8×10^{17} Mx in a basic magnetic element Stenflo deduced that the size of the elements was in the range 100-300 km. Stenflo (1975) later used these observations together with facular observations to derive a complete model atmosphere for the magnetic elements.

Wiehr (1976) used 3 lines of the same multiplet (6302, 6334, and 6408 Å) with Zeeman splitting factors from 1 to 2.5 to study strong network features with 2" resolution. Measured values of (B_ℓ) fell between 50 and 500 G. He tentatively confirmed the existence of a more or less unique field strength for network fields with $\langle B_\ell \rangle$ in the range 1200 to 1700 G and he inferred from varying amounts of measured flux that network elements are less than 400 km in size, faculae range from 500 to 900 km and pores are larger than 1100 km.

Livingston *et al.* are studying measurements of k using the same lines as Stenflo and have found real variations in k at a constant distance from line center. This might be due in part to varying velocity fields but it has been interpreted as due to differing amounts of Zeeman saturation. Using a two-component Unno model with the assumption of a uniform field inside the magnetic component, the result is a range of values of $\langle B_\ell \rangle$ from less than 500 G to 1700 G with a median of 1100 G. Livingston discovered that k values are dependent on μ, changing rather rapidly from μ = 1.0 to μ = 0.9 and more gradually to small values of μ. This result is tentatively identified with a drop in field strength with increasing height. This type of observation was also attempted on inner network fields but so far, without success. Svalgaard (1976) reports that K = 1.0 for observations of the Sun as a star which implies that a significant amount of flux exists at field strengths less than 500 G.

4. OTHER OBSERVATIONS

If the size and structure of a magnetic element could be measured then a determination of flux would allow the field strength to be inferred rather directly. We must be careful here to distinguish between tiny "basic" elements and clumps of such elements. Partial solar eclipses offer the possibility of measuring the time for a magnetic feature to be covered and thus its size. (An attempt to do this during an unfavorable eclipse at Kitt Peak by timing the uncovering of features failed for the simple reason that one never knows where a feature is until it is uncovered). At the Crimean Observatory, the last two transits of Mercury were used to determine the size of radio emission features (Efanov *et al.*, 1974) and magnetic, velocity and brightness features (Severny, 1976). No magnetic or radio structures smaller than 1".5 were seen. Speckle interferometry is a technique which involves rapid recording of an image with a very tiny scanning aperture. Provided the scanning is rapid enough, information at spatial scales as small as the diffraction limit of the telescope can be determined. I have attempted magnetic speckle observations at Kitt Peak so far without success. The problem is one of poor signal-to-noise ratio owing to the small scanning aperture required.

It is well known that brightenings observed in weak to moderately strong spectrum lines (Chapman and Sheeley, 1968; Chapman, 1972) and in the continuous spectrum near disk center (Liu, 1974; Skumanich *et al.*, 1975) are closely associated with magnetic fields. Very high resolution continuum photographs near disk center (Dunn and Zirker, 1973;

Mehltretter, 1974) show that the dimensions of local brightenings (filigree) associated with magnetic fields are as small as 100-200 km. If the brightenings strictly indicate the locus of the network field then there is good agreement between the filigree dimensions and the dimensions of field elements which can be inferred from various measurements discussed earlier. At present it is not clear if the filigree and the magnetic field are different manifestations of strictly the same structure. Simon and Zirker (1974) concluded that the field is more diffuse than the filigree while Beckers (1976), using observations like Figure 10, argues that the nearly perfect agreement he finds between bright features and areas showing circular polarization in the wing of a Mg line can be extrapolated slightly downward to the filigree structures. A rapid variation of flux tube diameter is required in the first 400 km above the photosphere in a recent model by Spruit (1976) in order to match center-to-limb variations in facular contrast.

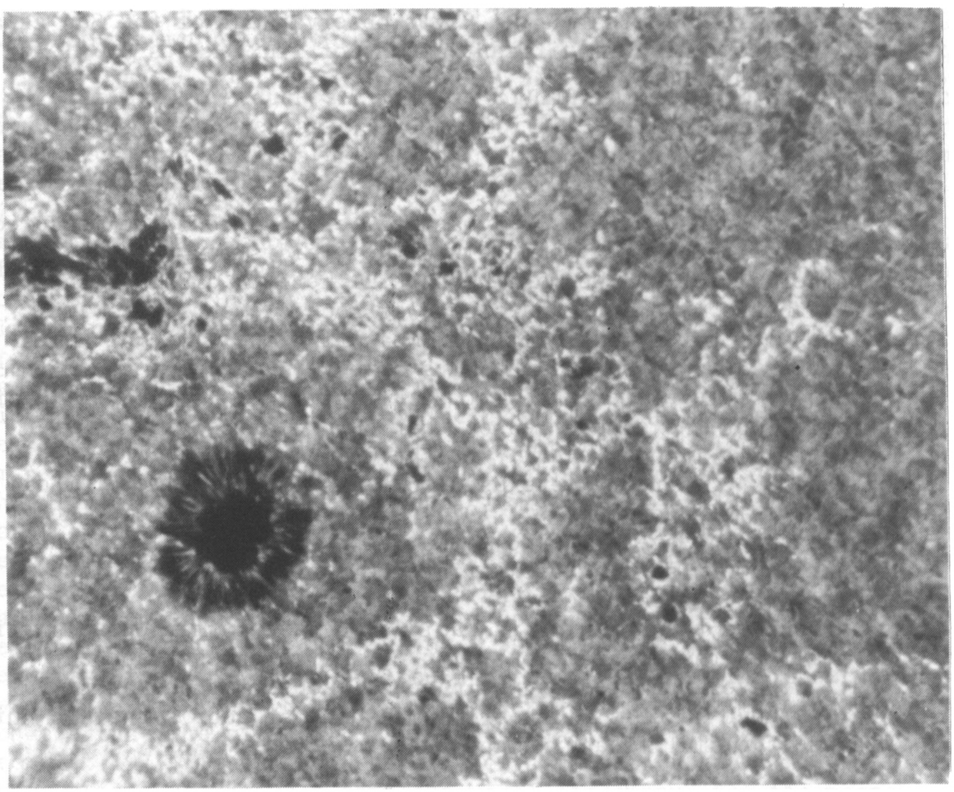

Figure 10. Filtergram taken 0.4 Å in the red wing of the Mg I line at 5183 Å near disk center on 8 May 1973. The bright network elements are cospatial with features showing large Zeeman effect. Scale is about 1" mm^{-1}. (Beckers, 1976)

Since just determining the structure and basic properties of small-scale magnetic fields is a very difficult observational problem, the determination of time variations is even harder and little is known with confidence. One serious problem is that in the presence of telescope polarization, instrumental crosstalk is possible between measured magnetic field and other parameters such as Doppler shift and brightness (Wiehr, 1971; Jäger, 1972). Motion pictures of network and inner network fields reveal horizontal motions with velocities rarely faster than 1 km s^{-1} (Smithson, 1973; Livingston and Harvey, 1975). Larger magnetic structures tend to be more stable. Stenflo (1975) has suggested that magnetic structures decay at a constant rate of -10^{15} Mx s^{-1} regardless of size but the observational evidence for this is rather indirect. Conflicting statements concerning oscillations of network field elements have been made and new observations are probably required to clarify this matter.

5. SUMMARY

It is likely that our picture of small-scale photospheric magnetic fields will continue to change rapidly in the future as it has in the past as new observations are made and analyzed. Therefore, any definitive conclusions are out of order. At the present, observers might be able to agree with most of the following statements regarding photospheric magnetic fields outside of sunspots:

1. There is no evidence for an unresolved "microturbulent" magnetic field.
2. Most of the magnetic flux observed with a resolution approaching 1" is concentrated into small elements but there is increasing evidence for the existence of an unknown amount of flux in the form of fields less than 500 G in strength.
3. The small elements tend to cluster into larger structures which can act cohesively so that a broad spectrum of sizes of magnetic structures is observed.
4. Magnetic flux tends to cluster in a network pattern which coincides with the boundaries of supergranule cells.
5. The main difference between network and active region magnetic fields is the number density of small flux elements.
6. The size of magnetic elements increases with increasing height.
7. Polarities are mixed on a small scale so that estimates of total magnetic flux are lower limits.
8. The fields are probably mainly vertical but observational evidence is very weak.
9. The field strength in magnetic elements decreases rapidly with increasing height.
10. At the height of formation of most photospheric lines at the disk center in network elements, a range of $\langle B_\ell \rangle$ values from less than 500 G up to 1900 G is found with a high sample frequency at around 1100 G.
11. Peak values of B_ℓ within network magnetic elements may exceed 2 kG.

12. Systematic downdrafts are associated with magnetic fields with mean values in the magnetic elements of 0.5 km s^{-1} at the height corresponding to the core of the 6103 Å line and 2.2 km s^{-1} at the lower height corresponding to the wings of the 15648 Å line.

It now seems clear that rather complicated models of the sort developed by Stenflo (1975), Chapman (1976) and Spruit (1976) are required to quantitatively interpret magnetic field observations. The reason is inadequate spatial resolution of the tiny magnetic elements and systematic association of the elements with differential velocities, line weakenings, temperature changes and gradients in these quantities.

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