MAGNETIC FIELD STRENGTHS DERIVED FROM VARIOUS LINES IN THE UMBRAL SPECTRUM

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Abstract. Profiles of various lines in the spectra of umbrae are discussed, emphasizing the use of purely umbral lines. In the dark core of a large umbra the field strengths measured from various lines are the same, yielding 3080 ± 50G. In regions with umbral dots the field strengths do depend on the spectral line; the strengths are lower than in the dark core. Some conclusions are discussed.

For the investigation of the magnetic field in umbrae of sunspots, purely umbral lines, i.e. Fraunhofer lines which are very weak in the photosphere and enhanced in the umbra, offer some advantages. First, the line profiles are not affected by stray light (Zwaan, 1966). Second, these lines originate mainly in the coolest columns of the umbra. Thus, even if the fine structure cannot be resolved in the spectrograms, some information on the correlation between magnetic and thermal inhomogeneities may be obtained from the comparison between measurements from purely umbral lines and deductions from lines which are also present in the photospheric spectrum.

We prepared a list of purely umbral lines with simple or otherwise interesting magnetic splitting patterns, selected on the appearance of the profiles. We used photographic spectrograms of a very large spot close to the center of the disk ($\vartheta = 13°$) recorded at Sacramento Peak Observatory on September 18, 1966. Line profiles were obtained in both opposite directions of circular polarization and, by subtracting, in Stokes parameter V. For comparison we could use density tracings from spectrograms of the same umbra recorded at Kitt Peak National Observatory. The latter spectrograms were obtained without a polarizing analyser, but the spectral resolution is higher and the noise is less.

One of the most suitable lines was found to be

Ti I, λ6064,626, low E.P. = 1.05 eV, $^{\mathrm{ph}}W_\lambda = 7\,\mathrm{m\AA}$, simple triplet, $g = 2.00$.

In the umbral spectrum this line is relatively free from blends, it is fairly strong and therefore it can also be observed in pores.

We recommend to use this line for routine measurements of umbral field strengths and for investigations where effects from the varying amount of stray light should be excluded, e.g., into the dependence of the field strength on the umbral area and into the changes of the field with time.

Up to now we measured magnetic field strengths from the profiles of 6 purely umbral lines (equivalent widths in the photosphere $^{\mathrm{ph}}W_\lambda \lesssim 10\,\mathrm{m\AA}$), 7 low-excitation photospheric lines ($^{\mathrm{ph}}W_\lambda > 30\,\mathrm{m\AA}$, strengthened or about equally strong in the umbra), and 1 high-excitation photospheric line (weakened in the umbra). The spectrograms refer to the *dark core* in the umbra where we have never seen any fine structure in the

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intensity, neither visually nor on overexposed photographs, during the full week we observed the spot. From these 14 lines we obtained

$$B = 3080 \pm 50\,\mathrm{G},$$

without any dependence on the type of the line. The uncertainties in the field strengths determined from individual lines range from 70 to 150G.

From this result we conclude that in the dark core there were no substantial magnetic inhomogeneities correlated with invisible inhomogeneities in temperature. Moreover, the components of the magnetic lines show widths very similar to the widths of purely umbral non-magnetic lines, which suggests little spread in the field strengths in the region of the dark core where the purely umbral lines are formed. In purely umbral lines with patterns where both the σ- and the π-components show a wide gap at the position of the unshifted line, we find, with Mehltretter (1969), no visible central component. This excludes that cool columns with much weaker fields would occupy a substantial fraction of the area.

From the discussion thus far we cannot exclude a possible existence of invisible hot elements with very weak fields. However, even if all umbral dots would reach photospheric conditions during a part of their evolution, transitional conditions are to be expected, both in space and in time. The results reported here indicate that the transitional conditions, if present, occupy a small area in the dark core.

The π-components do not seem abnormally strong in the purely umbral lines, even in the fairly strong line Ti I λ6064.6 the π-component is weak. 'Abnormal' shifts of the π-components (Severny, 1959; Hénoux, 1968; Moe and Maltby, 1968) cannot be observed in these lines. In some photospheric lines (e.g., λ6302.5 and λ6173) there may be a slight indication that the fairly strong π-components are somewhat shifted. However, we cannot find convincing evidence for an inversion in the origin of the V-profile, found by Beckers and Schröter (1968), which they tentatively interpreted as the result of inclusions of weaker fields with opposite polarity.

It should be mentioned that spectrograms from the dark core of the same spot, further from the center of the disk, do show strong π-components which are shifted. We have not yet deduced V-profiles from these spectrograms.

On the same date spectrograms were recorded from a region within the same umbra where rather faint umbral dots were visible. Provisional measurements with a comparator in the line Ti I λ6064.6 showed that the magnetic field strength is several hundreds of gauss smaller in the area with fine structure than in the dark core. This fits in with measurements in smaller spots (Zwaan, 1968). The conclusions may be summarized as follows:

(1) The strength of the umbral magnetic field depends on the fine structures such that the strongest fields are measured in dark cores, where no fine structures are visible. We suggest that this is at least one of the reasons for the intrinsic scatter in the routine measurements of field strengths in large spots.

(2) There is at least one case that in a dark core without visible fine structures the same field strength is obtained from different types of Fraunhofer lines.

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(3) In regions with visible fine structures the measured field strength does depend on the type of the spectral lines, in the sense that the fields measured in purely umbral lines are stronger than the fields obtained from photospheric lines (Zwaan, 1968). Apparently this effect cannot be explained by stray light alone, so it appears that the magnetic field strength is smaller in the hotter elements than in the cooler material in between.

From the above results it follows that the inhomogeneities should be taken into account in the determination of any depth dependence of the magnetic field from line profiles. For instance, it seems pointless to determine the vertical gradient $\partial B/\partial z$ from the field strengths measured in lines of different excitation and ionization potentials on the assumption of a homogeneous model, unless it can be demonstrated that the spectrograms from the investigated umbral region can indeed be explained by a homogeneous model.

Lists of suitable lines of different excitation and ionization potentials, with brief descriptions of the line profiles in the umbral spectrum, will be published elsewhere.

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Discussion

Mattig: Can you tell me something about the intensity-ratio between the dark part in the umbra and that part which is covered by umbral dots?

Zwaan: We have not evaluated the continuum intensities yet. The intensities relative to the photosphere in the green spectral region may amount to about 0.07 in the dark core and to about 0.10 in the region showing the faint dots.