

## ON THE TWO-COMPONENT STRUCTURE OF THE SUNSPOT MAGNETIC FIELD

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The magnetic intensification of Ti I, Ti II, Fe I, Fe II lines in the sunspot umbra is discussed, the data of Fricke and Elsässer (1965) and Makita (1963) being used. It is shown that high and low excitation lines are formed in the regions with different magnetic fields, the strength in the Fe II region is about two times smaller than in the Ti I. Direct measurements of magnetic splitting in Ti I and Fe II lines are in a good accordance with this result.

*О двухкомпонентной структуре магнитного поля в солнечных пятнах.* Исследуется магнитное усиление линий Ti I, Ti II, Fe I, Fe II в тени солнечных пятен по данным Фрике и Эльзассера (1965) и Макита (1963). Показано, что линии с высоким и низким возбуждением образуются в областях с различным магнитным полем, причем напряженность поля в области образования линий Fe II приблизительно в два раза меньше, чем в Ti I. Это различие подтверждается прямыми измерениями магнитного расщепления в линиях Ti I и Fe II.

It is known that simultaneous observations of Fe II, Sr II and C II lines on the one hand and Ti I and Fe I lines on the other in the same spot are hard to explain in the single model. The high excitation lines require high temperature and nearly photospheric conditions, the low excitation lines are explained only by temperatures 1500–2000° smaller than in the photosphere. This apparent difficulty led Makita (1963) to suggest the two component structure of the spot umbra. On the other hand, Zwaan (1965) expresses the opinion that all the Fe II lines in the spot umbra are due to the scattering of photosphere and penumbra light.

Direct measurements of magnetic splitting Fe II lines  $\lambda\lambda$  4924 Å and 5018 Å are made on the diffracti-  
onal spectrograph of the tower telescope IZMIRAN. These lines are seen to have considerable magnetic splitting. This splitting changes from one region in the umbra to another and usually has a maximum in the same places as splitting in the Fe I and Ti I lines. This structure of the Fe II lines in the umbra is impossible if the essential part of the line equivalent width is due to the scattering light from either the photosphere or penumbra, and this led us to the conclusion that they are not due to the scattering and the two-component structure of spot umbra does exist. This two-component structure of physical conditions seems to lead to differences of magnetic field strength in the line formation regions of Ti I and Fe II. The magnetic intensification effect of the spot lines gives us the possibility of determining the mean ratio of the field strength in these regions.

It was shown by Bojarčuk, Efimov and Stepanov (1960), that the logarithm of magnetic intensification has a linear growth against a value  $n\Delta g$ , the slope being proportional to the field strength. Here  $n$  is the number of left or right  $\sigma$ -components and  $\Delta g$  is the difference of the Lande factors of the upper and lower levels.  $\log W^*/W^\odot$  is plotted against  $n\Delta g$  for Ti I, Ti II, Fe I and Fe II lines, the data of Fricke and Elsässer (1965) with correction for scattering were used. For control this dependence for Ti I lines was discussed in the umbra and penumbra, using the observations of Makita. The value  $W^*/W^\odot$  depends not only on the magnetic intensification but also on the ratio of the effective temperatures and pressure in the umbra and photosphere, which may be different for different lines. Furthermore, the magnetic intensification itself is strongly dependent on the field orientation, line strength and turbulent velocities. Finally, the values  $W^*$  and  $W^\odot$  may contain considerable uncertainties either through measurements or through the correction for scattering, especially for weak lines. It is not surprising, therefore, that a great scattering of dots on the figures exist. In order to lower this scattering slightly we select medium lines placed on the middle part of the spot curve of growth. For those lines  $W^*$  and  $W^\odot$  measured more precisely, the magnetic intensification is the greatest and slowly depends on the small variations of the line strength. These values are plotted in Fig. 1. The coefficients of the formula  $\log W^*/W^\odot = an\Delta g + b$  computed by the least squares method, and the number of lines  $N$  are given in the table. The coefficient  $a$  describes the magnetic intensification and is proportional to the magnetic field strength; the term  $b$  gives the mean value of strengthening or weakening lines in the spot in the absence of magnetic intensification.

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Magnetic intensification in the Ti I lines is nearly in agreement with that computed by Bojarčuk, Efimov and Stepanov for the field strength  $H$  2500–3000 gs. The measurements of Fricke and Elsässer (1965) and Makita (1963) give the same value of the intensification in the umbra in Ti I lines within the limits of mean square errors. The intensification in the penumbra is about 3 times smaller than that in the umbra and it is just what was to be expected. The plotting of the expression  $\log W^\odot = a n \Delta g + b$  naturally gives the value  $a \approx 0$  in the photosphere within the limits of mean square errors.

The ratio of intensification in the Ti I and Fe I lines on the one hand and Fe II and Ti II on the other is of particular interest. From the Table 1 and Fig. 1 it may be seen that in hot regions, where the Fe II and possibly Ti II lines are formed, the magnetic field strength is about 2 times smaller than in the cold regions. Moreover, if we do not take into account some weak Ti I lines in the photosphere ( $\approx 10 \text{ m}\text{\AA}$ ) which are measured with great uncertainties (some points at the top of Fig. 1), the magnetic intensification in Ti I and the ratio of the field strength in cold and hot regions would be greater. It should be noted that if we take all the

Table 1

N	Fricke and Elsässer				Makita	
	Ti I	Ti II	Fe I	Fe II	Ti I, umbra	Ti I, penumbra
	32	20	17	11	11	21
a	$0.086 \pm 0.045$	$0.031 \pm 0.027$	$0.067 \pm 0.012$	$0.041 \pm 0.032$	$0.077 \pm 0.035$	$0.024 \pm 0.020$
b	$0.553 \pm 0.077$	$-0.050 \pm 0.030$	$0.218 \pm 0.019$	$-0.210 \pm 0.043$	$0.395 \pm 0.041$	$0.144 \pm 0.024$

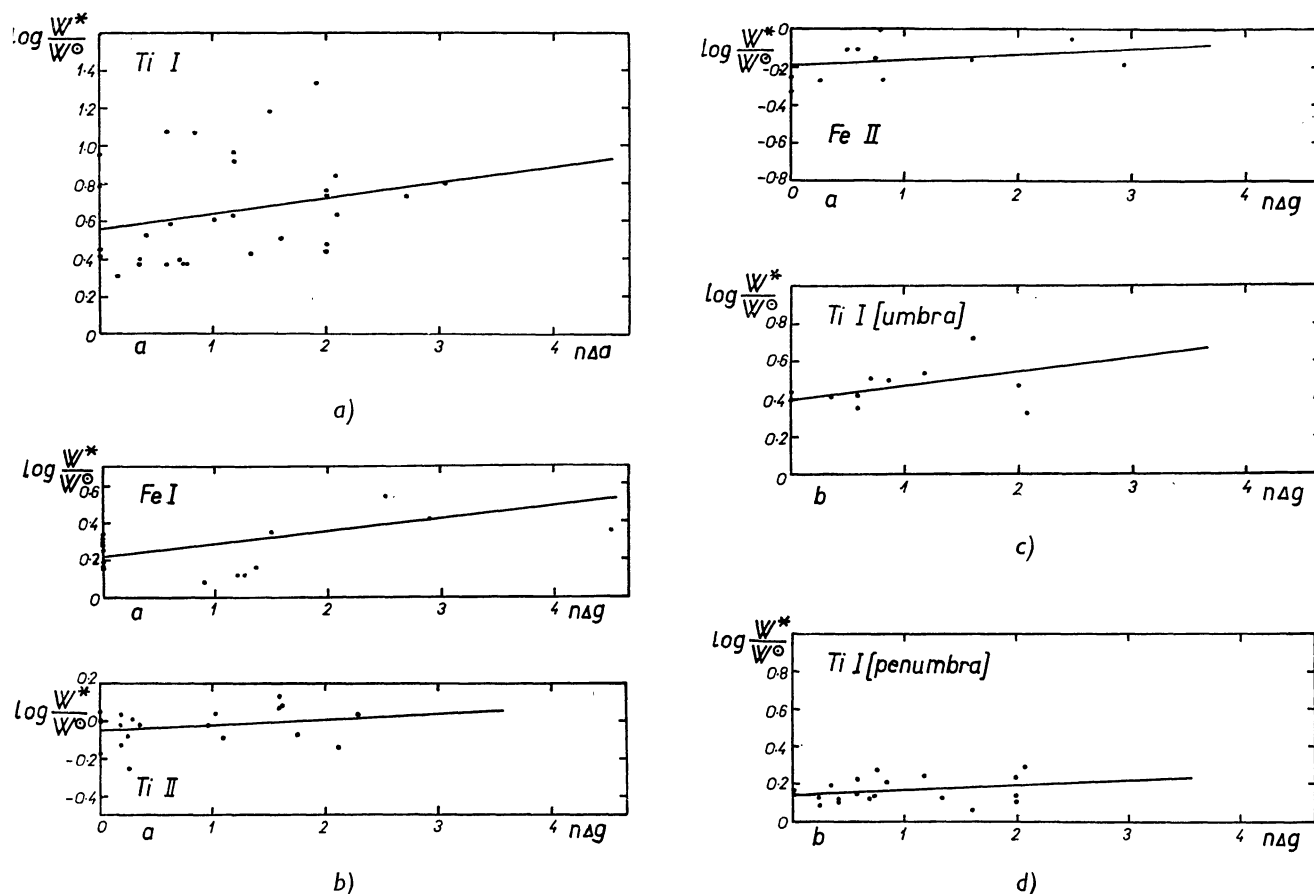


Fig. 1. Magnetic intensification in the Ti I, Ti II, Fe I and Fe II in the umbra for Fricke and Elsässer data and separately in the Ti I in the umbra and penumbra for Makita data.

lines measured by Fricke and Elsässer, the scattering of points on the plot is increased, but nevertheless the magnetic intensification in the Ti I lines is still greater than in the Fe II lines. And if we take measurements with no reduction for scattering, this effect will be seen also. Finally, if we take lines of one multiplet only (9 lines of multiplet n 38 for Ti I and only 5 lines of multiplet n 49 for Fe II, see Fig. 2) we have  $a = 0.085$ ,  $b = 0.35$  for Ti I and  $a = 0.020$ ,  $b = -0.31$  for Fe II, i.e. the magnetic intensification in Fe II is about 4 times smaller than in Ti I. This effect is not due to bad correction for the scattering of photosphere light because in the photosphere the dependence of  $W^\odot$  on  $n\Delta g$  is absent.

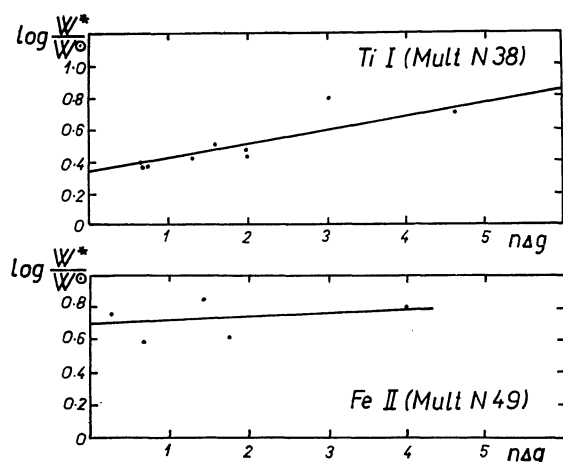
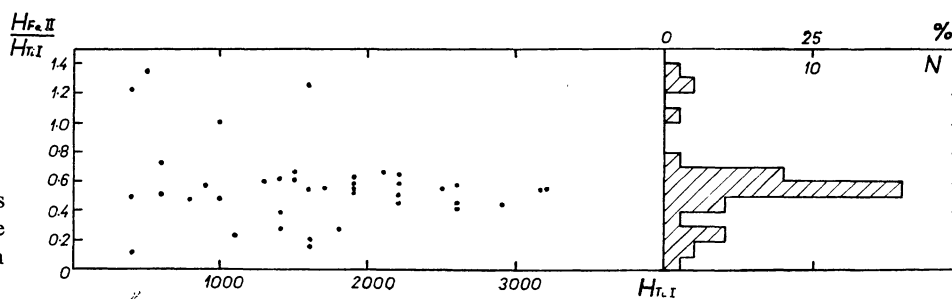


Fig. 2. Magnetic intensification in multiplets Ti I and Fe II (Fricke and Elsässer data).

To control this result we made direct measurements of the magnetic field strength in the lines Fe II  $\lambda\lambda$  5018.45 and 4923.93 Å, Fe I  $\lambda\lambda$  5016.89 and 4924.78 Å, Ti I  $\lambda\lambda$  5020.03 and 5016.17 Å. These measurements are in a good accordance with the results of magnetic intensification. Measurements in 40 places in the umbra and penumbra of a great spot are presented in Fig. 3. The ratio of the field strength in Fe II and Ti I lines is plotted against the field strength in Ti I and the histogram of this ratio is given to the right. The mean value of this ratio is 0.55. For 70% of all measurements  $0.4 \leq H_{\text{Fe II}}/H_{\text{Ti I}} \leq 0.6$  and only in 4 cases (10%) the magnetic field in Fe II lines exceeds that in Ti I lines.

Fig. 3. Ratio of magnetic fields in the Fe II and Ti I lines. The histogram of this ratio is given to the right.



It is interesting that in Fe I lines the magnetic intensification is somewhat smaller than in Ti I lines. This result is very uncertain, the difference of intensifications in both elements is in the limits of mean

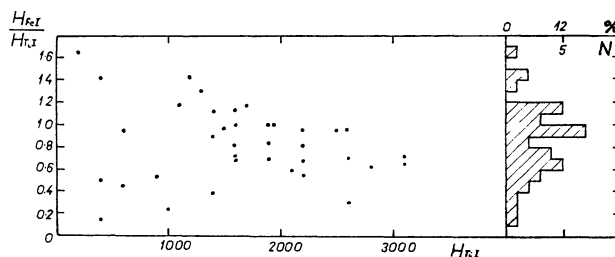


Fig. 4. Ratio of magnetic fields in the Fe I and Ti I lines. The histogram of this ratio is given to the right.

square errors. But direct measurements also show that the magnetic field strength in Fe I lines is a little smaller than in Ti I (see Fig. 4). The mean value of the ratio  $H_{\text{Ti I}}/H_{\text{Fe I}} = 0.83$ . In 70% this ratio is smaller than 1.0. But in this case the scattering of the ratio values is greater than for a comparison of the magnetic field strengths in Fe II and Ti I lines. It should be mentioned that two and more maxima on the histograms (see Figs. 3 and 4) give the impression that the magnetic field in a sunspot has not only two but possibly more components.

These results are in a good accordance with the suggestion of a very inhomogeneous magnetic field in a sunspot which is composed of some magnetic elements or "subgranules" (Mogilevskij et al. 1967).

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#### REFERENCES

- Bojarčuk A. A., Efimov J. S., Stepanov V. E., 1960, AŽ 37, 812.  
 Fricke K., Elsässer H., 1965, ZfA 63, No. 1, 35.  
 Makita M., 1963, Publ. Astr. Soc. Japan 15, 2, 145.  
 Mogilevskij E. I., Demkina L. B., Ioshpa B. A., Obridko V. N., 1967, Proc. Symposium on the Structure and Development of Solar Active Region, Sept. 1–9, Budapest.  
 Zwaan C., 1965, Recherches astronomiques de l'observatoire d'Utrecht, XVII (4).