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Evolution of sunspots seen in molecular lines. I*

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Abstract. With a view to assess the role of changing magnetic field strengths on line intensities, the results of equivalent width calculations of some lines of C_2, MgH and TiO molecules are presented here for standard photospheric and sunspot model atmospheres. Such an approach is expected to throw some light on evolution of sunspots and on a better structuring of semi-empirical sunspot models by way of correct evaluation of scattered photospheric light.

Key words : sunspots—magnetic field—scattered light—line intensities

1. Introduction

The scattered photospheric light has been the bane of many sunspot observations (Lambert *et al.* 1971; Sinha 1982a). Brants & Zwaan (1982) have demonstrated how the use of an iron line in previous studies, invariably lead to an underestimate of magnetic field strengths in spots of small diameters. Owing to several problems, including estimate of scattered light, numerous observers tend to restrict themselves to observing well developed large sunspots only and to consider the umbrae of spots as a homogeneous medium for the purpose of model making. Whether the spots of dissimilar diameters represent different umbral atmospheres or not, has been an important area of study. Zwaan (1965) discussed this aspect also and found that the observational evidence is far from being conclusive. Recently, Sobotka (1985) studied spots of different sizes and constructed model atmospheres also which are different from each other. However, studies on such lines which could elucidate better the evolution of sunspots, are lacking in the literature. We examine here the possible use of C_2, MgH and TiO lines to determine the physical conditions in small as well as big sunspots. A simultaneous study of photospheric and spot observations with the help of these molecules is expected to take care of scattered light also.

The appearance of a sunspot is noticed with the emergence of a pore which may or may not later develop in to a large sized spot. Also, spots of different sizes are expected

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to possess different magnetic fields (Zwaan & Brants 1981; Brants & Zwaan 1982). Since the magnetic field has the effect of cooling in a sunspot atmosphere, it seems reasonable to assume that spots with different magnetic fields or sizes should be representing different physical conditions. Now, if we pose the problem as follows, we have interesting consequences.

Let us introduce a growing magnetic field in a small region of the otherwise quiet photosphere. As the field strength grows, more and more cooling is produced. This should be observable in spectral scans too. It is well known that C_2 Swan bands are essential features of the photospheric spectrum and too weak for detection in sunspots (Harvey 1972). Similarly, TiO Alpha bands are found in spots and not in photosphere (Wöhl 1970). As an in-between case, the MgH Green bands are recorded as extremely weak lines in the photospheric spectrum (Schadee 1964) and only as weak lines in spots (Sotirovski 1971). The band heads of these molecular transitions fall in a small spectral region $\lambda_{0,0}(C_2) = 5265$ Å, $\lambda_{0,0}(\mathrm{TiO}) = 5166$ Å and $\lambda_{0,0}(\mathrm{MgH}) = 5212$ Å. This is a wavelength region where the opacity code is well understood. This makes us take up a study of some lines belonging to these molecules and to see theoretically how the line intensities change as functions of magnetic field.

2. Method and calculations

Sunspot models with a varying magnetic field are sparse in literature. Stankiewicz (1967), beginning with a photospheric model due to Minnaert (1953), evolved a set of five model atmospheres as functions of magnetic field, very close to the problem mentioned above. However some of his assumptions are only preliminary. We utilized the sunspot models with the magnetic field strength H given as 1500G, 2000G, 2500G, 3000G and 3500G (Stankiewicz 1967). These models are hereinafter referred to as M(2), M(3), M(4), M(5) and M(6) respectively. The Avrett (1981) sunspot model referred to as M(7) has been utilized only for the purpose of comparison. The photospheric model due to Holweger & Müller (1974) is utilized here and has been referred to as M(1).

The various sources for data etc. are summarised below:

Molecular transition : C_2 Swan bands $(d^3\pi_g - a^3\pi_u)$
MgH Green bands $(A^2\pi_r - X^2\Sigma^+)$
TiO alpha bands $(C^3\Delta_r - X^3\Delta_r)$.
Dissociation energies : $D_0^0\ (C_2) = 6.11$ eV (Huber & Herzberg 1979)
$D_0^0\ (\mathrm{MgH}) = 1.27$ eV (Balfour & Lindgren 1978)
$D_0^0\ (\mathrm{TiO}) = 6.87$ eV (Huber & Herzberg 1979).
Oscillator strengths : $f_{0,0}\ (C_2) = 2.39 \times 10^{-1}$ (Lambert 1978)
$f_{0,0}\ (\mathrm{MgH}) = 1.1 \times 10^{-1}$
$f_{0,1}\ (\mathrm{MgH}) = 2.9 \times 10^{-3}$ (Tomkin & Lambert 1980)
$f_{0,0}\ (\mathrm{TiO}) = 5.8 \times 10^{-2}$ (Steele & Linton 1978).
Wavelengths & line identifications : Sinha (1984), Sotirovski (1971).
Molecular constants : Huber & Herzberg (1979).
Atomic abundances : $\epsilon(\mathrm{C}) = 8.67$, $\epsilon(\mathrm{O}) = 8.92$ (Lambert 1978)
$\epsilon(\mathrm{Mg}) = 7.62$ (Lambert & Luck 1978)
$\epsilon(\mathrm{Ti}) = 5.08$ (Blackwell *et al.* 1982).

Atomic partition functions: Irwin (1981).
Dissociation constants : Sinha & Joshi (1982), Tsuji (1973).
Microturbulence : 2.1 km s^{-1} (Porfirèva 1986)
0.85 km s^{-1} (Brault *et al.* 1982).
Hönl-London factors : Kovacs (1969), Schadee (1964).

The paper by Larsson (1983) served as a good reference for correct expressions for band oscillator strengths and rotational intensity factors. Owing to observational difficulty, sunspot observations for close limb positions such as cos $\theta = 0.2$ are not available. We completed calculations for cos $\theta = 0.2$ to illustrate how the selected lines might behave in a centre to limb study.

3. Results and discussion

The partial pressures of the molecules C_2, MgH and TiO in the seven considered model atmospheres are compared in figure 1. Because of the effects of the well known CO formation (Branch 1969), one can note that C_2 formation gets affected adversely as one moves from photospheric to umbral atmospheres. It also has the effect of moving the C_2 forming layers to deeper depths in sunspots. Tables 1a and 1b summarize our results of equivalent width (EW) calculations at cos $\theta = 1.0$ and 0.2 respectively. Though we used the values of microturbulence from photospheric observations, they represent a good range in values obtained from sunspot observations (Stellmacher & Wiehr 1970). This

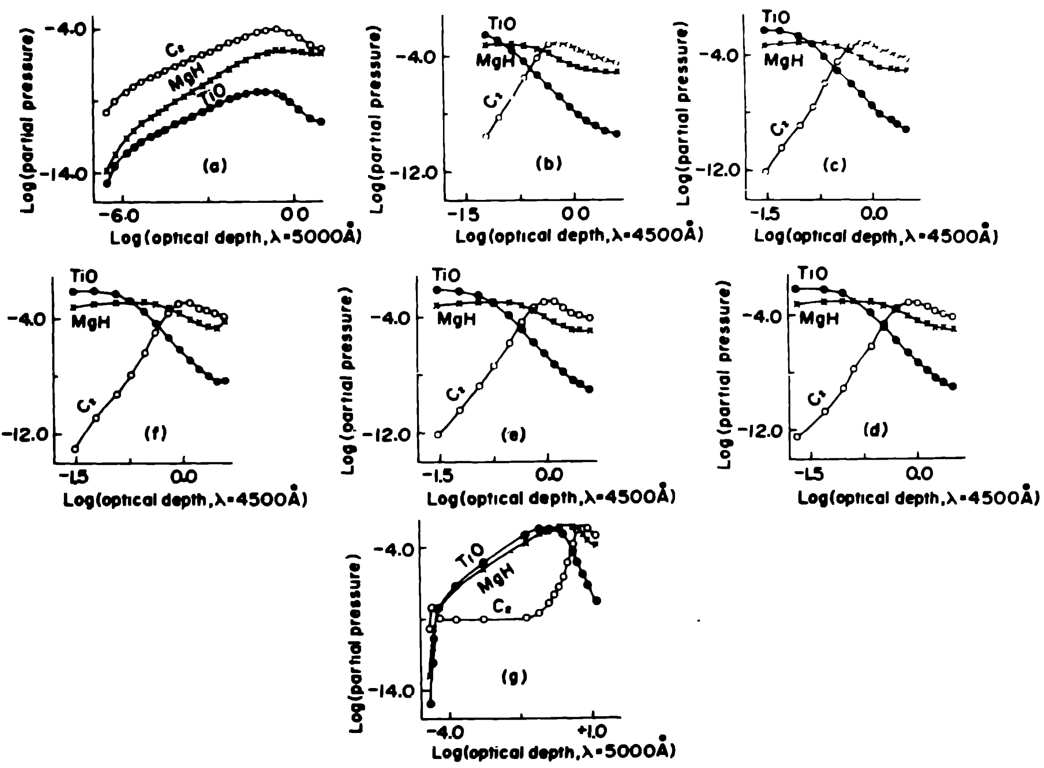

Figure 1. A comparison of the partial pressures of the molecules C_2, MgH and TiO in photospheric and sunspot models. The symbols a, b, c, d, e, f and g refer to plots for the models M(1), M(2), M(3), M(4), M(5), M(6) and M(7) respectively (*cf.* text).

Table 1a. Comparison of observed and calculated line intensities of C_2, MgH and TiO molecules in photosphere and sunspot umbrae for the centre of the solar disc.

Wave-length (Å)	Branch (J/K)	‡Observed		Equivalent widths (mÅ) Calculated													
		Photo-sphere	Spot	M(1)		M(2)		M(3)		M(4)		M(5)		M(6)		M(7)	
				$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$
(0-0) band of $(d^3\pi_g - a^3\pi_u)$ transition of C_2																	
5132.360	R_1 (18)	8.0	—	7.0	7.1	14.5	15.1	12.1	12.6	13.4	14.0	13.8	14.5	13.1	13.8	2.3	2.4
5136.440	R_2 (15)	7.5	—	6.1	6.2	12.8	13.2	10.7	11.1	11.9	12.4	12.2	12.8	11.6	12.1	2.1	2.2
5140.381	R_3 (12)	4.5	—	5.1	5.2	10.9	11.2	9.1	9.4	10.2	10.5	10.5	10.9	10.0	10.3	1.8	1.8
5150.558	$P_1(36)+$ $P_2(35)$	12.5	—	15.8	16.4	29.4	31.8	24.2	26.4	26.2	28.8	26.3	29.2	25.3	28.0	4.4	4.9
5159.453	P_1 (28)$^+$	13.8	—	15.4	16.4	28.9	31.3	23.9	26.0	25.8	28.4	25.9	28.7	25.0	27.5	4.3	4.8
5159.470	P_2 (27)																
5160.385	P_3 (25)	6.5	—	7.7	7.9	15.8	16.4	13.2	13.8	14.6	15.3	14.9	15.7	14.2	15.0	2.5	2.6
(0-0) band of $(A^2\pi - X^2\Sigma)$ transition of MgH																	
5061.536	Q_2 (37)	2.9	58	1.5	1.5	55.6	80.7	69.9	101.0	78.7	115.0	75.2	111.0	78.2	116.0	83.9	117.0
5085.178	Q_1 (33)	—	59	2.0	2.0	51.6	78.7	65.8	99.7	75.4	113.0	70.8	107.0	72.9	111.0	85.5	123.0
5106.848	R_2 (16)	3.7	61	1.7	1.7	43.6	68.3	54.7	85.0	69.0	102.0	61.2	93.2	61.7	94.6	82.5	123.0
5190.561	P_2 (29)	1.0	72	1.2	1.2	53.6	78.9	66.9	99.0	75.7	113.0	71.8	107.0	73.9	112.0	83.3	117.0
5202.985	P_1 (24)	1.9	61	1.4	1.5	49.5	76.0	62.0	95.0	72.9	109.0	67.5	102.0	69.0	105.0	84.2	122.0
5207.78	P_2 (10)	1.5	64	1.1	1.1	46.5	71.9	57.0	88.2	69.6	103.0	63.1	95.7	63.8	97.1	83.3	121.0
(0-1) band of $(A^2\pi - X^2\Sigma)$ transition of MgH																	
5520.23	R_1 (13)	—	16	†3.4E-2	3.4E-2	11.0	11.4	17.8	18.8	22.4	23.7	24.2	25.9	29.1	31.7	23.7	26.1
5550.68	Q_2 (17)	—	29	6.3E-2	6.3E-2	17.6	18.6	27.2	29.6	33.6	36.8	35.7	39.8	41.8	47.5	33.5	38.4
5555.52	R_2 (8)	—	13	2.5E-2	2.5E-2	8.7	8.9	14.4	15.0	18.2	19.1	19.7	20.8	24.1	25.8	19.4	20.9
5583.57	Q_1 (10)	—	24	5.5E-2	5.5E-2	17.1	18.1	27.0	29.4	33.5	36.8	35.5	39.5	41.6	47.4	32.9	37.6
5596.76	P_1 (22)	—	12	3.0E-2	3.0E-2	8.4	8.6	13.4	13.8	16.7	17.4	18.4	19.3	22.3	23.7	18.5	19.9
5603.94	P_2 (20)	—	17	3.0E-2	3.0E-2	8.6	8.8	13.7	14.3	17.2	18.0	18.9	19.8	22.9	24.4	18.8	20.2

(Continued)

Table 1a. Continued

(0-0) band of $(C^3\Delta - X^3\Delta)$ transition of TiO

5189.80	P_2 (31)	—	10	1.7E-4 *[1.4E-4]	1.7E-4	14.4 [13.0]	18.5	30.0 [29.9]	51.6	39.3 [39.0]	60.6	34.9 [34.8]	61.2	37.4 [37.7]	68.6	39.2 [35 4]	51.1
5199.01	P_3 (39)	—	12	2.0E-4 [1.6E-4]	2.0E-4	15.2 [13.8]	19.9	30.1 [30.2]	52.9	39.6 [39.3]	69.8	35.0 [35.1]	62.4	37.4 [37 8]	69.4	41.1 [37.4]	54.6
5199.82	R_3 (60)	—	18	2.3E-4 [1.8E-4]	2.3E-4	15.3 [13.8]	20.0	30.7 [30 7]	53.4	40.0 [39 8]	70.4	35.6 [35.6]	63.0	38.2 [38.6]	70.6	41.2 [37 5]	54.8
5211.77	R_1 (70)	—	17	2.2E-4 [1.8E-4]	2.2E-4	14.5 [13 0]	18.5	31.1 [30.7]	52.1	40 3 [39.8]	69.3	36.0 [35 8]	62.1	39.1 [39 3]	70.0	39 1 [35.3]	50.9
5213.03	P_1 (50)	—	18	2.2E-4 [1.8E-4]	2.2E-4	15.5 [14.1]	20.5	30.3 [30 5]	53.7	39.9 [39.7]	70.6	35.3 [35.4]	63 2	37.7 [38.2]	70.2	41.9 [38 2]	56 1
5249.03	R_2 (90)	—	12	1.7E-4 [1.4E-4]	1.7E-4	11.5 [10.0]	13.6	30 2 [28 5]	44.2	39.6 [38 0]	61.1	35 7 [34.2]	54 7	40 3 [39.4]	65.6	31.3 [29.8]	38.2

*Quantities within brackets correspond to Titanium abundance from Grevese *et al* (1989)

†E ± n = $10^{\pm n}$

¶The observed equivalent widths for the (0-0) band of MgH and for the (0-0) band of C_2 in photosphere are from Lambert *et al.* (1971) and Sinha (1984) respectively. The spot observations refer to Sotirovski (1971).

Table 1b. Comparison of observed and calculated line intensities of C_2, MgH and TiO molecules in photosphere and sunspot umbrae for a near limb position on the solar disc.

Equivalent widths (mÅ)

Wave-length (Å)	Branch (J/K)	Observed		Calculated													
		Photo-sphere	Spot	M(1)		M(2)		M(3)		M(4)		M(5)		M(6)		M(7)	
				$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$
(0-0) band of $(d^3\pi_g - a^3\pi_u)$ transition of C_2																	
5132.360	R_1 (18)	12.0	—	13.1	13.8	9.9	10.9	7.9	8.8	5.8	6.5	4.3	4.8	3.3	3.7	6.2E-3	6.3E-3
5136.440	R_2 (15)	13.8	—	11.6	12.2	9.0	9.8	7.2	8.0	5.3	5.9	3.9	4.4	3.0	3.3	5.4E-3	5.5E-3
5140.381	R_3 (12)	8.0	—	10.0	10.4	7.9	8.5	6.4	7.0	4.7	5.2	3.5	3.8	2.7	2.9	4.6E-3	4.6E-3
5150.558	P_1 (36) + P_2 (35)	20.6	—	24.8	27.5	15.7	18.6	12.1	14.4	8.8	10.4	6.8	7.9	4.8	5.8	13.3E-3	13.0E-3

(Continued)

Table 1b. Continued

Wave-length (Å)	Branch (J/K)	Observed		Equivalent widths (mÅ) Calculated													
		Photo-sphere	Spot	M(1)		M(2)		M(3)		M(4)		M(5)		M(6)		M(7)	
				$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$	$\xi=0.85$	$\xi=2.1$
5159.453	P_1 (28)$^+$	21.8	—	24.4	27.1	15.6	18.4	12.1	14.3	8.7	10.4	6.7	7.9	4.8	5.8	13.3E-3	13.4E-3
5159.470	P_2 (27)																
5160.385	P_3 (25)	11.5	—	14.1	14.9	10.4	11.5	8.2	9.2	6.0	6.8	4.5	5.0	3.4	3.8	6.4E-3	6.4E-3
(0-0) band of ($A^2\pi - X^2\Sigma$) transition of MgH																	
5061.536	Q_2 (37)	—	—	2.6	2.6	30.5	48.0	46.2	72.4	59.2	89.5	47.5	74.2	48.2	75.7	22.2	33.8
5085.178	Q_1 (33)	—	—	3.4	3.5	27.0	41.6	40.4	63.1	52.7	83.5	41.4	65.5	42.0	66.3	22.9	32.6
5106.848	R_2 (16)	—	—	3.1	3.1	23.3	34.9	33.3	50.1	42.6	67.0	34.4	52.3	34.7	52.3	25.6	34.0
5190.561	P_2 (29)	—	—	2.0	2.1	28.3	44.7	42.0	66.3	55.2	85.8	43.3	68.7	43.5	69.3	21.6	32.6
5202.985	P_1 (24)	—	—	2.6	2.6	25.5	39.3	37.2	57.9	48.7	78.0	38.2	60.2	38.5	60.3	22.6	31.9
5207.780	P_2 (10)	—	—	2.0	2.0	24.0	36.8	34.1	52.4	44.4	71.2	35.2	54.8	35.2	54.3	23.0	32.0
(0-1) band of ($A^2\pi - X^2\Sigma$) transition of MgH																	
5520.23	R_1 (13)	—	—	6.1E-2	6.1E-2	24.1	27.6	37.8	45.4	44.4	54.0	40.5	50.0	43.5	55.2	11.6	13.4
5550.68	Q_2 (17)	—	—	11.1E-2	11.1E-2	31.4	38.6	46.3	59.6	53.3	69.7	47.7	63.2	49.9	67.6	15.0	18.3
5555.52	R_2 (8)	—	—	4.4E-2	4.4E-2	20.3	22.7	33.1	38.6	39.3	46.4	36.1	43.2	39.5	48.5	9.9	11.2
5583.57	Q_1 (10)	—	—	9.7E-2	9.7E-2	30.8	37.8	45.8	59.2	53.0	69.6	47.2	62.8	49.4	67.3	14.8	18.1
5596.76	P_1 (22)	—	—	5.3E-2	5.3E-2	19.6	21.7	31.3	35.9	36.8	42.5	34.2	40.1	37.4	44.9	9.2	10.4
5603.94	P_2 (20)	—	—	5.2E-2	5.2E-2	20.0	22.1	31.9	36.8	37.6	43.7	34.8	41.1	38.0	45.9	9.4	10.6
(0-0) band of ($C^3\Delta - X^3\Delta$) transition of TiO																	
5189.80	P_2 (31)	—	—	†4.3E-4	4.3E-4	13.4	26.2	19.2	40.7	30.1	61.6	22.4	47.3	22.8	48.3	17.2	27.8
5199.01	P_3 (39)	—	—	4.9E-4	4.9E-4	13.1	26.1	18.8	40.0	29.5	61.1	21.9	46.5	22.5	47.5	17.3	28.5
5199.82	R_3 (60)	—	—	5.6E-4	5.6E-4	13.2	26.4	19.4	41.2	30.3	62.3	22.6	47.7	23.3	49.1	17.3	28.5
5211.77	R_1 (70)	—	—	5.3E-4	5.3E-4	13.8	26.6	20.5	43.3	31.9	63.6	23.8	49.6	24.6	51.5	17.1	27.6
5213.03	P_1 (50)	—	—	5.5E-4	5.5E-4	13.0	26.2	18.9	40.1	29.5	61.4	22.0	46.7	22.6	47.8	17.3	28.8
5249.03	R_2 (90)	—	—	4.2E-4	4.2E-4	15.0	25.7	24.1	48.6	35.4	65.0	27.5	53.6	28.7	56.7	15.9	23.8

†E ± n = $10^{\pm n}$.

Sunspot observation for such a position (cos $\theta = 0.2$) do not exist. For the photospheric observations of the (0-0) band of C_2, refer to Sinha (1984).

also helps in assessing the role of different values of microturbulence on EWs of the lines considered here.

We utilized model M(1) here because of its ability to reproduce the observed photospheric rotational temperature of the molecules C_2 for the centre of the solar disc (Sinha 1984). The other photospheric model due to Maltby *et al.* (1986) found in literature is very close to the model M(1) except in the chromosphere. This model shall be included in a future study. Now we proceed to discuss the C_2, MgH and TiO molecules separately.

The molecules C_2

The molecular constants of C_2 have been studied in great detail (Phillips & Davis 1968). Also the oscillator strength borrowed from Lambert (1978) is in close agreement with $f_{0,0} = 0.032 \pm 0.002$ found in a recent investigation (Stark & Davis 1985). So, *a priori*, a good agreement in photospheric observations and calculations is not ruled out. We, in fact obtain a good match between observations and calculations for one line each of the R_1, R_2, R_3, P_1, P_2 and P_3 branches in the photosphere. Also, as expected, the higher value of microturbulence yields higher EWs. Barring a slight drop in model M(3), the equivalent widths are almost unchanged by the varying magnetic field at $\cos\theta = 1.0$ and $\cos\theta = 0.2$. For $\cos\theta = 1.0$, the EWs for the sunspot models M(2), M(3), M(4), M(5) and M(6) are all higher than those for model M(7) and are also higher than the photospheric value, in contrast to observations (Harvey 1972). For $\cos\theta = 0.2$, the EWs show a dip in sunspots but a gain in photosphere. The CO formation was considered in our calculations and it seems that higher photospheric EWs only indicate the preliminary nature of the Stankiewicz (1967) sunspot models which are derived from an old photospheric model due to Minnaert (1953).

The molecules MgH

For the lines of the (0-0) band of the Green system of photospheric MgH, the agreement between calculations and observations is remarkable as in the case of C_2. This ensures the reliability of the input parameters such as the dissociation energy and the oscillator strengths (*cf.* Kirby *et al.* 1979; Sinha 1982b). The disagreement between spot observations and calculations is attributed to an underestimate of scattered photospheric light (Sinha 1982a).

The stronger photospheric MgH lines strengthen with magnetic field and assume almost a constant value beyond $H = 2500$G. This behaviour was explained by Gaur *et al.* (1971) in terms of 'temperature' and 'pressure' effects in case of the molecules CO. We believe that due to excess formation of molecules in models with increasing magnetic field, the MgH lines tend to get saturated. The lower values of EWs at 3000G may be a consequence of the approximate nature of the chosen model. The centre-to-limb behaviour of EWs (table 1b) gives results similar to those in table 1a.

As an alternative to the saturated lines of the (0-0) band of MgH, we also present our results for the (1-0) band of the same molecules in tables 1a and 1b. The six chosen lines are absent in photospheric spectrum and show an increase towards the solar limb. also they sense the change in magnetic field better.

The molecules TiO

This molecule has been the subject of many laboratory studies (Sinha 1978). Davis *et al.* (1986) give $f_{2,0} = 0.031 \pm 0.006$ in excellent agreement with $f_{2,0} = 0.030$ due to Steele &

Linton (1978). Both the investigations assumed an independence of $R_c(\bar{r})$ upon $\bar{r}$. However, the r independent value of $R_c(\bar{r})$ yields $f_{0,0} = 0.051$ and $\bar{r}$ dependent value of the same quantity yields $f_{0,0} = 0.058$ (Steele & Linton 1978). We prefer the latter value as a result of a general case. The small difference is inconsequential for the purpose of the present study.

In tables 1a and 1b the EWs obtained with a slightly different abundance of Titanium due to Grevesse *et al.* (1989) are also presented. We find negligible effects on EWs due to slight changes in titanium abundance.

The alpha bands are found absent in photospheric spectrum as expected (*cf.* tables 1a and 1b). The predicted EWs, as in case of MgH, are not in agreement with sunspot

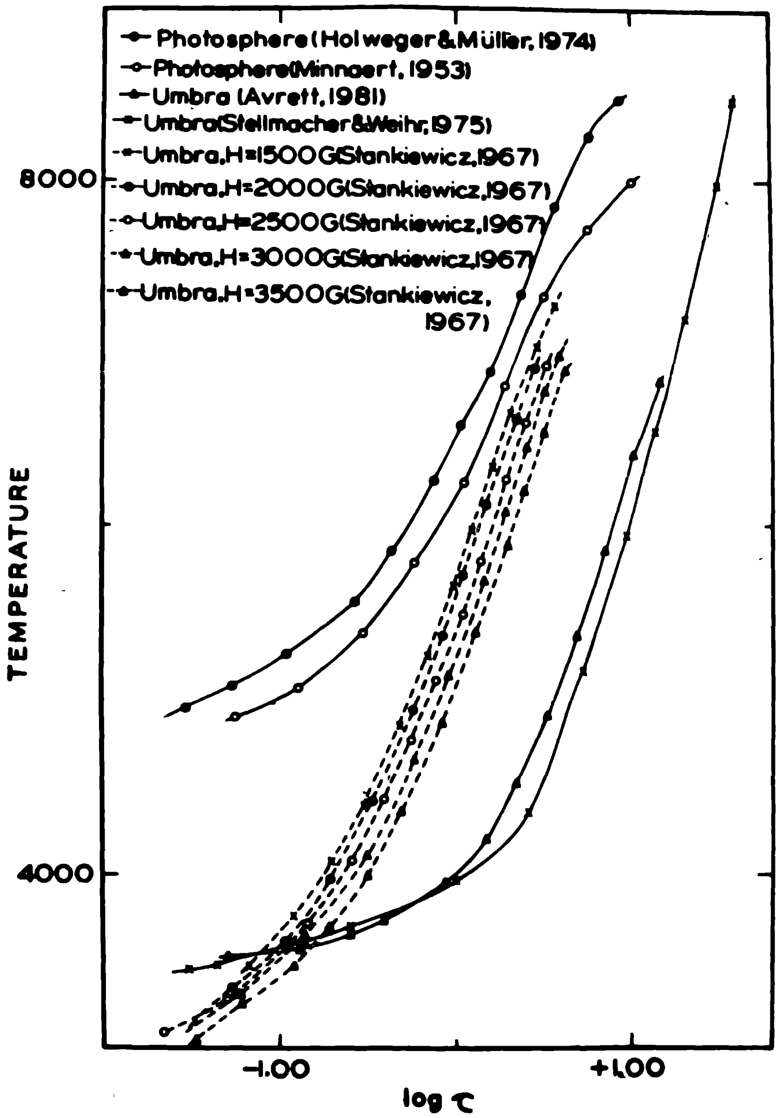

Figure 2. A comparison of the sunspot models due to Stankiewicz (1967) with the present day models due to Avrett (1981) and Stellmacher & Wiehr (1975). The Minnaert (1953) photospheric model from which the Stankiewicz (1967) models are derived, is also compared with a largely accepted photospheric model due to Holweger & Müller (1974).

observations. Again, we believe that this is due to under correction for the scattered photospheric light in observations.

The TiO lines which do not appreciably show a centre-to-limb variation in intensity are seen to strengthen with magnetic field up to $H = 2500$ G. Thereafter, the lines appear to get saturated and show, practically no difference in intensity with increase in magnetic field.

Limitations of Stankiewicz's (1967) model atmospheres

The five sunspot models proposed by Stankiewicz (1967) as functions of magnetic field appear only preliminary. Some of the points in this direction have already been elaborated upon by Gaur *et al.* (1971). In addition, it is only natural to find that Minnaert's (1953) photospheric model from which Stankiewicz (1967) models are derived can no longer be assumed as valid today (*cf.* figure 2). It differs substantially from the model M(1) due to Holweger & Müller (1974). The model M(1) is considered to be the best representative photospheric model today (Chmielewski 1984; Lambert 1984; Sinha 1984). Also this model is very close in the photospheric layers, to a recently proposed model by Maltby *et al.* (1986). Further, the different sunspot models due to Stankiewicz (1967) are not even close to the two sunspot models due to Avrett (1981) and Stellmacher & Wiehr (1975) as seen in figure 2.

4. Conclusions

Inspite of the weaknesses of the sunspot models M(2), M(3), M(4), M(5) and M(6) due to (Stankiewicz 1967) we have been able to show how the use of C_2, MgH and TiO lines can lead to a better understanding of sunspot atmospheres as outlined in the introduction. We are of the opinion that these molecular lines should be observed simultaneously in spot and photosphere to get better sunspot models. Such observations beginning with the appearance of a pore, its development to a well developed spot and finally decay can be expected to throw light on the evolution of sunspots. Further, it is felt that reliable theoretical models as functions of magnetic field are needed and in this context the Stankiewicz (1967) models need improvements. A detailed study is in progress which takes into account the spot diameter and the effect of different phases of solar activity on sunspot atmospheres.

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