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THE WEAKENED AND OBLITERATED LINES IN THE SUN-SPOT SPECTRUM

By G. NAGARAJA

Of the diverse features in the spectra of sun-spots the widened lines alone have received the greatest attention from observers. They are no doubt the most conspicuous. Several lists of them have been published, but so far some other peculiarities of the spot spectrum are only just beginning to receive attention. Especially is this the case with the weakened and obliterated lines. They have certainly been long recognized as characteristic of spots, but their number and character have yet to be properly estimated. Dr. W. M. Mitchell in an exhaustive catalogue of spot-affected lines between *a* and F has recorded for a total of 680 such lines about 50 as enfeebled.[1] In a later list and in connection with an allied phenomenon in spots, "the reversed lines," he has increased their number.[2] Messrs. Hale and Adams in their photographic observations of the spectra of spots have included but 26 weakened lines in a catalogue of about 345 which are affected in spots.[3] In another paper[4] dealing with the temperature of spots they have taken into account only 32 enfeebled lines for the whole region from λ 4060 to λ 5860. Professor Fowler[5] has considered about 30 weakened lines which he has found to belong to the high levels of the chromosphere. Some visual observations of mine on several large spots made me suspect that the weakened lines in spots were far more numerous than has been previously recorded. I have recently been enabled through the kindness of Mr. Evershed to obtain spectrum photographs of the large spots of May and June last. He found a concave parabolic grating belonging to Professor Michie Smith to be very good and mounted it for me in the Rowland spectrograph instrument of this observatory. This grating has a ruled surface of 1.8 inches (4.57 cm) with 15 028 lines to the inch (2.54 cm) and its focal length for parallel rays is 10 feet (3.05 meters), the radius of curvature being 20 feet (6.10 meters). By the use of a collimating lens the plates are actually exposed at a distance of about 12 feet (3.66 meters)

[1] *Astrophysical Journal*, **22**, 4, 1905.

[2] *Ibid.*, **24**, 78, 1906.

[3] *Ibid.*, **23**, 11, 1906.

[4] *Ibid.*, **24**, 185, 1906.

[5] *Monthly Notices*, **66**, 361, 1906.

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from the grating. Astigmatism is avoided by placing the camera tube normal to the grating and using approximately parallel light. A solar image of about 4 inches (10.16 cm) diameter is formed on the slit by a Grubb lens of 6 inches (15.24 cm) aperture and 40 feet (12.20 meters) focus fed by a siderostat. A sliding shutter with V-shaped aperture is arranged on the slit-plate, which enables the length of the slit to be varied between wide limits, thus allowing different lengths of exposure to be made for spot and sun. The definition of the grating is fine and the resolution is very good in the third order, which on one side is particularly bright.

Several excellent photographs were obtained of the region of spectrum between D and F. Rather long exposures were needed, notwithstanding the brightness of the grating, on account of the small angular aperture of the 40-foot lens; usually between 3 and 4 minutes were required for a spot, and 30 seconds for the adjacent photosphere,[1] this ratio giving approximately equal densities to the two spectra under the atmospheric conditions prevailing here. The linear dispersion is about 1.45 tenth-meters per millimeter and the definition is good enough to show the close doubles b_3 and 5316.8 distinctly resolved on the negatives.

An examination of the plates indicates quite clearly that the previous estimates of the number of weakened lines in sun-spots have been too low. I have carefully gone over the portion D to F on the photographs and have catalogued (leaving all doubtful cases) clear instances of 167 lines which are either thinned, weakened, or obliterated in spots. That is about half as many as the widened lines in the same region. As to the general character of these enfeebled lines, they are all of intensities in the sun ranging from 5 to 000 on Rowland's scale. The enfeeblement is generally through one or two intensities on the same scale. The greatest has been through 4, observed in the case of a few lines belonging to iron. I have included in the table at the end only those that varied through one or more units. Half or intermediate intensities might have been used and would have added more to the list, but I was afraid it would involve doubtful cases. One chief

[1] A small direct-vision prism is generally used in front of the slit to separate the different orders, and this, or the use of absorbing solutions, further reduces the intensity of the spectrum.

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characteristic of the enfeeblement is that it is solely a feature of the umbrae of spots. The weakened lines differ in this respect from the reinforced lines, which, except in the case of spot-bands, generally encroach into the penumbra. We could also easily recognize in the photographs certain types among the enfeebled lines. Some are merely thinned, others are weakened and appear a few shades less dark in the spot than in the sun. Among the latter several seem diffusedly to extend to either red or violet side and in rare cases on both sides. One class of lines, generally of small intensity in the sun, are wholly obliterated in the spots.

The first question with regard to these lines will be as to what extent they are characteristic of spots, whether they are a permanent feature or occur only in single spots. There is, however, nothing to warrant the latter view except perhaps the meager and scattered character of previous observations. It may be stated in this connection that visual observations of the weakened lines are by no means easy. Very fine weather and spots with large umbrae seem to be essential. They fail to catch the eye as readily as the widened lines. That is probably one explanation why the observations are so few. It may be plausibly suggested, however, that this phenomenon may be characteristic of some active spots only. But I have observed them in some quiet ones which showed no sort of disturbance as is usually indicated by the behavior of the hydrogen lines. The spots of May and June from the spectrum photographs of which the accompanying catalogue has been prepared did not appear to belong to the class of active spots. At least at the time when the plates were exposed there was no disturbance going on.

But if it be asked whether the same lines are affected in all spots or in the same manner it is certainly too early to attempt a definite answer to the question. Dr. Mitchell has expressed the opinion that they vary and that he has found more weakened lines in 1906 than in 1905.[1] My own impression, however, is that there is not much variation. I have compared the different observations for the region D to F. Of the 26 lines contained in Hale and Adams' catalogue, 22 are in my list. It was quite a surprise to me that even the estimates of the degree of enfeeblement were either the same or very close in

[1] *Astrophysical Journal*, 24, 78, 1906.

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TABLE I

TABLE OF WEAKENED AND OBLITERATED LINES IN SUN-SPOT SPECTRUM PHOTOGRAPHED AT KODAIKANAL IN MAY AND JUNE 1907 SOLAR LATITUDE OF SPOT, 12 AND 13 SOUTH

Wave-Length	Origin	Intensity in Sun	Intensity in Spot	Remarks
4874.196	*Ti*	o	oo	p-*Ti*(Lockyer) almost obliterated in Hale's map
4874.926	*Ni*	o	oo	
4875.215	—	o	oo	
4876.586	*Cr*	1	o	p-*Cr* (Lockyer); Mitchell gives maximum weakening
4893.997	—	oo	—	Obliterated; see Note 1
4894.743	—	oo	—	Obliterated
4900.301	*Y*	2	1	p-*Y* (Lockyer)
4912.666	*Cr*	ooo	—	p-*Cr* (Lockyer). Obliterated
4914.150	—	2	1	Weakens and also seems to thin on the red side
4916.426	—	ooo	—	Obliterated
4918.190	*Fe*	1	o	Weakens and also thins on violet side
4924.107	*Fe*	5	3	p-*Fe* (Lockyer). Chromospheric line
4925.450	*Fe*	oo	ooo	Mitchell gives a line at λ 4925.75, probably this
4936.015	*Ni*	2	1	
4937.245	—	oo	—	Obliterated
4937.524	*Ni*?	3	2	Thinned
4945.622	*Ni*	1	oo	
4945.814	*Fe*	1	o	
4946.215	*Ni*	o	oo	Almost obliterated in Hale's map
4947.778	—	oo	ooo	
4965.351	*Ni*	o	—	Obliterated
4974.431	—	ooo	—	Obliterated; a broad dark spot-band falls over the place
4984.297	*Ni*	2	1	
4985.432	*Fe*	3	2	
4986.403	*Fe*	1	o	
4987.088	—	oo	—	Obliterated
4995.586	—	oo	—	Obliterated; a broad spot-band falls over the lines and extends to the violet side
.835	—	oo		
4996.558	—	ooo	—	Obliterated
4997.024	*Ni*	1	o	
4998.408	*Ni*	1	o	Thinned; Mitchell gives maximum intensity
4999.207	*Fe*	o	oo	Mitchell gives a line at λ 4999.69, probably this
5008.825	—	ooo	—	Obliterated; spot-band falls over the place. Only weakened in Hale's map
5010.396	—	oo	—	Obliterated
5013.871	—	o	oo	
5014.100	—	oo	—	Obliterated
5022.414	*Fe*	3	2	Weakened only slightly in Hale's map; see Note 2
5023.372	*Fe*	o	oo	Hale's map shows a spot-band over the place which is not seen in my photographs
5027.937	*Fe*	1	oo	Mitchell gives this line
5048.242	*Ni*	o	ooo	
.409	—	oo		
5052.338	—	o	—	Obliterated
5057.665	*Fe*,*Ni*	o	oo	A bright band falls over the line
5072.479	*Ti*	o	—	p-*Ti* (Lockyer). Obliterated
5082.526	*Ni*	2	o	Hale and Mitchell give in their list, but is not clearly shown in Hale's map

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TABLE I—*Continued*

Wave-Length	Origin	Intensity in Sun	Intensity in Spot	Remarks
5084.279	*Ni*	3	2	A bright line falls just to the red side and thins the line on that side
5086.422	—	oo	—	Obliterated; a bright band falls over the line
5087.601	*Y?*	1	oo	Chromospheric line
5089.134	*Ni*	0	oo	
5094.594	*Ni*	1	0	
5103.142	*Ni*	1	0	Thinned
5115.566	*Ni*	2	1	A bright line falls just to the red side
5115.961	*Fe*	0	oo	
5118.112	*Mn*	oo	ooo	Thinned; bright bands fall on both sides of the line
5119.292	—	oo	—	Obliterated
5121.732	*Ni*	0	0	Hale and Mitchell give the line
.825	*Fe*	2		
5129.805	*Fe*	1	—	Obliterated; a broad dark band falls over the region. See Note 3
5132.843	—	oo	—	Obliterated; Hale gives the line
5140.992	—	oo	—	Obliterated
5147.273	—	ooo	—	Obliterated
5154.579	—	ooo	—	Obliterated; see Note 4
5158.152	—	oo	ooo	
5159.231	*Fe*	2	1	Hale and Mitchell give the line; see Note 5
5164.724	*Fe?*	1	0	Hale and Mitchell give the line
5165.080	*C*, —	ooo	—	Thins on the red side
5170.937	*Fe*	0	—	There is a close widened line on the red side
5176.737	*Ni*	1	ooo	A bright band on violet side encroaches into the line and thins it
5178.970	—	oo	—	
5186.073	*Ti*	2	1	p-*Ti* (Lockyer). Weakened and diffusedly extending to violet side
5188.079	*Fe*	1	0	Weakened and diffusedly extending to red side
5197.332	*Ni,Mn*	oo	ooo	
5197.743	—	2	ooo	p-*Fe* (Fowler). Chromospheric line
5198.108	—	0	oo	
5211.700	*Fe*	oo	ooo	Thinned
5213.515	—	ooo	—	Obliterated; Rowland's intensity for the line is too small
5215.737	—	ooo	—	Obliterated
5218.085	*Fe*	0	1	
.369	*Fe*	1		
5220.358	*Ni*	0	oo	
5226.707	*Ti*	2	1	p-*Ti*. Thinned; chromospheric line
5234.791	—	2	0	p-*Fe* (Fowler). Chromospheric line
5236.373	—	0	oo	
5237.497	*Cr*	1	oo	p-*Cr*. Weakened and diffusedly extending both ways
5239.992	—	1	oo	Weakened and diffusedly extending to red side
5257.100	*Sr?*	oo	ooo	
5264.976	—	0	oo	Hale gives the line
5271.464	—	oo	—	Obliterated
5275.148	—	0	—	Obliterated
5280.239	*Cr*	oo	—	p-*Cr*. Obliterated
5284.281	*Ti*	1	oo	Mitchell gives the line; thinned and weakened

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TABLE I—*Continued*

Wave-Length	Origin	Intensity in Sun	Intensity in Spot	Remarks
5284.787	—	oo	—	Obliterated
5292.762	*Fe*	o	oo	Weakened and diffusedly extending to violet side
5293.211	Awv?	oo	—	Obliterated; Mitchell gives this as a chromospheric line
5294.134	*Fe*	o	oo?	
5294.726	—	oo	ooo	Thinned
5306.040	*Cr?*	o	oo	5306.3 p-*Cr* (Lockyer)
5316.790	*Fe*	4	3	p-*Fe*. Hale and Fowler give the line; chromospheric line
5317.724	—	oo	—	Obliterated
5325.738	—	2	1	Fowler gives the line; chromospheric line.
5335.050	*Cr*	1	o	p-*Cr* (Hale). 5335.5 p-*Cr* (Lockyer)
5336.974	*Ti*	4	3	p-*Ti* (Lockyer)
5337.910	—	o	oo	Hale gives the line
5342.890	*Co*	1	o	
5359.389	*Co*	oo	—	Obliterated
5363.058	—	3	2	p-*Fe* (Fowler). Chromospheric line
5377.028	*Fe*	o	oo	Thinned
5381.221	*Ti*	2	1	p-*Ti* (Lockyer). Rowland gives this as belonging to *Fe*
5409.339	*Fe*	2	1	The line is thinned on red side but extends far into the violet side in spot
5411.428	*Ni*	1	o	Thinned
5414.279	—	o	—	Obliterated
5425.464	—	1	o	Hale and Mitchell give the line
5478.668	*Cr*	o	ooo	p-*Cr*
5494.063	—	o	—	Obliterated
5502.297	—	o	oo	
5503.286	*Fe*	1	o	Weakened and thinned
5508.840	*Cr*	o	—	p-*Cr*. Obliterated
5510.229	*Ni*	1	o	
5519.797	*Fe*	o	oo	Thinned
5527.033	*Sc*	3	2	p-*Sc* (Fowler)
5532.202	—	oo	—	Obliterated
5532.968	—	1	o	
5535.061	*Fe*	2	1	
5539.507	*Fe*	o	—	Obliterated
5560.434	*Fe*	2	1	
5561.464	—	oo	—	Obliterated; Hale's map does not show it
5620.715	*Fe*	oo	ooo	
5625.541	*Ni*	o	ooo	Thinned
5625.904	—	oo	—	
5636.925	*Fe*	o	ooo	
5637.339	*Ni*	1	o	
5637.632	*Fe*	1	o	
5640.538	—	o	—	
5641.206	—	1	o	
5645.830	*Si*	1	ooo	Hale and Mitchell give the line
5649.898	*Fe,Ni*	o	oo	
5650.209	*Fe*	1	oo	
5650.911	*Fe*	1	o	
5651.691	*Fe*	o	ooo	
5659.817	*Fe*	o	ooo	

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TABLE I—*Continued*

Wave-Length	Origin	Intensity in Sun	Intensity in Spot	Remarks
5665.775	*Si*	1	oo	
5666.899	—	o	oo	
5669.258	—	1	o	Hale and Mitchell give the line
5669.962	*Ni*	o	—	
70.163	—	o		
5682.427	—	2	o	
5684.710	*Si*	3	o	Hale and Mitchell give the line
5686.757	*Fe*	3	2	
5690.646	*Si*	3	2	Hale and Mitchell give the line
5701.323	*Si*	1	ooo	Hale and Mitchell give the line
5704.960	A	o	oo	
5708.622	*Si*	3	1	Hale and Mitchell give the line; diffusedly extends to red side
5714.380	*Fe*	o	—	Obliterated
5731.984	*Fe*	4	3	Mitchell gives the line; not shown in Hale's map
5752.254	*Fe*	4	3	Weakened and diffusedly extending both ways
5753.860	*Cr*	1	oo	
5757.037	*Fe*	2	1	
5772.364	*Si*	3	1	Hale gives the line; diffusedly extending to red
5784.879	*Fe*	1	—	Obliterated
5785.498	*Fe*	3	1	
5793.292	—	3	2	Not shown in Hale's map
5798.077	—	3	1	Hale and Mitchell give the line; but not shown in Hale's map
5804.681	*Fe*	o	—	Obliterated; Mitchell gives the line; not shown in Hale's map
5831.821	*Ni*	1	o	
5835.645	—	oo	ooo	
5855.300	*Fe*	1	o	
5856.312	*Fe*	2	1	

[1] A faintly dark shading is seen just to the violet side of where this line ought to be in the spot.

[2] Hale and Adams give the line as decreased in weak arc.

[3] There is a p-*Ti* line close to the line at λ 5129.32.

[4] A bright line appears in the spot in place of the Fraunhofer line over a dark band that falls over the region. There is p-*Ti* close at λ 5154.24.

[5] A diffused dark band extends to red side from the line.

all the 22 cases. As to the remaining 4 lines which I had not included, I found they had all been given by Hale and Adams only a weakening of half an intensity on the Rowland scale. They had therefore been excluded from my table. Probably this close agreement between different observers could have been possible only by the photographic method in the study of the sun-spot spectrum. Fowler's method of estimating intensities should also be responsible for some of this accuracy. There is, however, less agreement between Mitchell's observations and mine, and I have noted in the table all those found in the former's

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TABLE II (SUMMARY OF TABLE I)

Elements	Number of Weakened Lines in Spots	Number of Widened Lines in Spots	Enhanced Lines Weakened in Spots	Enhanced Lines Not Weakened in Spots	Remarks
Unknown....	59	94	—	—	
Fe.....	48	50	5	2	
Ni.....	26	7	—	—	
Si.....	7	—	—	—	
Ti.....	7	48	6	1	
Cr.....	9	42	8	—	(1)
Co.....	2	5	—	—	
Y.....	2	—	1	—	
Sc.....	1	—	1	—	
Mn.....	1	13	—	—	

Rowland's identifications *Ni*, *Mn*, *Sr?*, *C*, —, *A*, *A* (*wv*) have each one weakened line in the region.

[1] There is one *Cr* line at λ 5753.860 about which it is not known whether it is enhanced or not, as Lockyer's tables have not been extended to that wave-length.

TABLE III (CHROMOSPHERIC LINES)

Wave-Length	Origin	Observers [2]	Level of Chromosphere	Weakened or not	Remarks
4861.527 (F)[1]	*H*		High level		
4883.869	*Yt* (earth)	N.	Low level	No	
4900.301	*Y?*	Y. N.	Low level	Yes	p-*Y* (Lockyer)
4921.963	*La-Ti*	Y. N.	High level	No	
4924.107	*Fe*	Y. N.	High level	Yes	p-*Fe* (Lockyer)
4934.214	*Ba*	Y. N.	High level	No	
.277					
4993.699	—	N.	Low level	No	
.864	*Fe*				
5015.9	*He*	Y. N.	High level	No	
5018.629	*Fe*	Y. N.	High level	No	p-*Fe* (Lockyer)
5087.601	*Y?*	N.	Low level	Yes	
5167.497	*Mg*	Y. N.	Low level	No	
.678 b_4	*Fe*				
5169.069	*Fe*	Y. N.	High level	No	p-*Fe* (Lockyer)
.220 b_3					
5172.856 b_2	*Mg*	Y. N.	High level	No	
5183.791 b_1	*Mg*	Y. N.	High level	No	
5186.073	*Ti*	F.	Low level	Yes	p-*Ti* (Lockyer)
5188.863	*Ti*	Y. N.	Low level	No	p-*Ti* (Lockyer)
5197.743	*Fe*	Y. N. F.	High level	Yes	p-*Fe* (Fowler)
5200.355	*Cr*	N.	Low level	No	
.590	*Va*				
5204.1	—	N.	Low level	No	
5205.897	*Y*	N.	Low level	No	
06.265	*Cr-Ti*				
5208.596	*Cr*	N.	Low level	No	
.776	*Fe*				
5226.707	*Ti*	Y. N. F.	Low level	Yes	p-*Ti* (Lockyer)

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TABLE III—*Continued*

Wave Lengths	Origin	Observers[2]	Level of Chromosphere	Weakened or not	Remarks
5234.791	*Fe*	Y. N. F.	High level	Yes	p-*Fe* (Fowler)
5237.497	*Cr*	F.	High level	Yes	p-*Cr* (Lockyer)
5264.976	—	F.	High level	Yes	
5269.723 E_2	*Fe*	Y. N.	Low level	No	
5276.169	*Fe?*	Y. N.	High level	No	
5284.281	*Ti*	Y. F. N.	High level	Yes	
5316.790	*Fe*	Y. N. F	High level	Yes	p-*Fe* (Lockyer)
5325.738	—	N. F.	High level	Yes	
5328.696	*Fe*	N.	Low level	No	
.747					
5336.974	*Ti*	F.	High level	Yes	p-*Ti* (Lockyer)
5363.058	*Fe*	Y. N. F.	High level	Yes	p-*Fe* (Fowler)
5371.656	*Cr?*	N.	Low level	No	
.734	*Fe*				
5381.221	*Ti*		High level	Yes	p-*Ti* (Lockyer)
5397.344	*Fe*	N.	Low level	No	
5405.989	*Fe*	N.	Low level	No	
5425.464	—	H. M. F. N.	High level	Yes	
5429.991	*Fe*	N.	Low level	No	
5434.740	*Fe*	N.	Low level	No	
5447.130	*Fe*	N.	Low level	No	
5455.671	*Fe?*	N.	Low level	No	
.834	*Fe*				
5527.033	*Sc*	N. F.	High level	Yes	p-*Sc* (Fowler)
5535.061	*Fe*	Y. N. F.	High level	Yes	

[1] Wings of $H\beta$ obliterated in spot which therefore appear narrower than on photosphere. $H\delta$ on another plate taken about the same time is very much weakened in spot.

[2] Y refers to Young, F to Fowler, M to Mitchell, H to Hale, and N to the present writer.

TABLE IV (SUMMARY OF TABLE III)

CHROMOSPHERIC LINES—44

WEAKENED IN SPOTS 18				NOT WEAKENED IN SPOTS 26			
High Level 14		Low Level 4		High Level 9		Low Level 17	
Enhanced 9	Not Enhanced 2	Enhanced 3	Not Enhanced 1	Enhanced 2	Not Enhanced 7	Enhanced 1	Not Enhanced 16
Fe−5	*Fe*−1	*Ti*−2	*Y*−1	*Fe*−2	*Mg*−2	*Ti*−1	*Fe*−12
Ti−2	*Ti*−1	*Y*−1			*La, Ti* 1		*Cr*−3
Cr−1					*Fe?* 1		*Mg*−1
Sc−1					*Ba*−1		
					H−1		
Unknown 3					*He*−1		

catalogue. Nearly all the lines given by Fowler are in my list and are also noted. But what bears most on the point is that almost

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all the lines in my catalogue are distinctly enfeebled in the reproductions of the Mount Wilson photographs of spot spectra which we recently received from Professor Hale. Of the 167 lines in my list only 7 are not shown in the reproductions. Of these 4 are of very low intensity in the sun and are completely obliterated in my photographs. It would thus appear that Hale and Adams in the preliminary study of their photographs did not particularly look for this phenomenon but simply recorded those that thrust themselves on their notice when they were examining the plates for the widened lines. We may then as a result of this close agreement conclude that between the time of the Mount Wilson photographs, which were taken probably some time during the latter part of 1905, and the middle of the present year, there has not been any noticeable variation of the weakened lines in the spectra of sun-spots.

I shall next consider some points of interest disclosed in the catalogue. In the summary (Table II) I give a list of the elements concerned, with the number of weakened lines in each case. And as it may be useful to compare the behavior of the same elements in the production of the widened lines, I have given the latter as well. These are extracted from the tables of Hale and Adams[1] and relate to very nearly the same reigon as I have dealt with. In the light of the connection that has been recently traced between the enfeebled lines in spots and the enhanced lines of some of the elements I have, along with noting them in the larger list, summarized them also, in Table II.

Comparing the weakened with the strengthened lines in spots we find that a large proportion in both cases are of unknown origin. Then comes iron, contributing nearly an equal number to either phenomenon. There are about 250 other iron lines in the same region which are probably unaffected in spots. We can only gather that as between the two cases iron does not seem to have any particular partiality. But not so some of the other elements. Most of the titanium and chromium lines are widened, while the nickel and silicon lines exhibit a similar partiality for weakening. The last, it should be noted, has all its lines in the region enfeebled.

With regard to the enhanced lines that are represented in the list, I am indebted to Mr. Evershed for the identification of most of them.

[1] *Astrophysical Journal*, 23, 28, 1906.

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Reference has already been made to the 32 weakened lines which Hale has considered in his paper on the temperature of spots and of which he has found 29 to be spark lines. There is, however, nothing like this proportion disclosed in my table and the enhanced lines form by no means a large fraction of the total number. But it is to be remarked that Hale has included in his inquiry the more refrangible part of the spectrum, which is especially rich in enhanced lines, and also that complete tables are not available for the other regions. Still, within the portion I have considered, there are about 40 spark lines belonging to iron, titanium, and chromium which are found in Lockyer's tables, and 4 more which have been recently noted by Fowler to be enhanced. Of these 19 are found in the catalogue, and 10 are too little affected to be included in it, but still they appear to be slightly weakened.[1] In the case of the rest, most of them are only of small intensity in the spark and a few are too faint to be seen either in the sun or in the spot. There are, however, some 5 instances of enhanced lines of tolerable intensity in the spark not being affected at all in the spot. They are λ 5169.07 and λ 5169.22 belonging to iron, λ 5188.87 to titanium, and λ 5502.9 and λ 5621.7 to chromium. Thus, though it cannot be said that most of the weakened lines in spots are spark lines, we see, however, that a great majority of the latter are weakened in spots. It is also to be noticed that almost all the titanium and chromium lines weakened in spots are spark lines of those elements. The only exception is that of λ 5284.281, which Rowland has identified as belonging to titanium, but which is not found in Lockyer's table of enhanced lines. In the case of iron, while most of the spark lines in the region dealt with are weakened, yet a large majority of the weakened lines of this element are not spark lines, or have not as yet been identified as such. We have already seen that iron was concerned almost equally with producing both the widened and weakened lines, while titanium and chromium contribute mostly to the widened lines. It is then significant that when some lines of the two last elements suffer weakening in spots they should be almost all enhanced lines. Messrs. Hale, Adams, and Gale have from the laboratory experiments found that the spark lines of iron,

[1] Two more enhanced lines are in the list, one of which has been assigned by Fowler to "proto-scandium" and the other by Lockyer to "proto-yttrium."

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titanium, chromium, and vanadium, when passing to a weak arc, are either weakened or obliterated, while the ordinary arc lines are all strengthened.[1] This would lead to the conclusion that the conditions prevailing in spots are analogous to the weak arc, and the Mount Wilson observers have so inferred. It might certainly account for the enhanced lines being weakened in spots. But this view alone cannot explain the presence of so many other weakened lines in spots which have not yet been identified as spark lines.

It may also be interesting to compare the chromospheric lines with those weakened in spots, and Table III has been prepared for that purpose. Only the lines found in the chromosphere between F and D are considered. Most of them have been observed by me and their character as high- or low-level lines determined. To make the table complete as far as possible I have included five other lines from Fowler's list.[2] A summary has also been added (Table IV) from which we gather that only a fraction of the chromospheric lines are weakened in spots. It is brought out further that a good many of the weakened lines belong to the higher levels of the chromosphere; but at the same time the contrary statement cannot be made. This would imply that the cause of weakening is not to be traced to the mere circumstance of these lines being present in the upper chromosphere. An examination of Table IV further discloses that a large majority of the weakened lines in it are also enhanced lines. Leaving out the 3 unknown lines, we find 12 out of the 15 to be spark lines. It has already been noticed that the latter tended generally to weaken in spots. The enfeebling then in the present instance of most of the chromospheric lines that are also weakened in spots may be accounted for solely on the ground of their being enhanced lines at the same time. The predominance of the high-level lines of the chromosphere among the weakened may also be explained by the larger number of the enhanced lines being found in those levels.

In bringing this paper to a close I wish to express my thanks to Mr. Evershed for the valuable help he has given me in the course of its preparation.

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[1] *Astrophysical Journal*, 24, 185, 1906. [2] *Monthly Notices*, 66, 364, 1906.

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