PECULIARITIES AND CHANGES OF FRAUNHOFER LINES INTERPRETED AS CONSEQUENCES OF ANOMALOUS DISPERSION OF SUNLIGHT IN THE CORONA.[1]

By W. H. Julius.

Attention has been drawn to several variable peculiarities of Fraunhofer lines, mainly by Jewell's investigations on the coincidence of solar and metallic lines.[2] Here we do not mean the irregularities occurring in the spectrum of spots or of faculæ, which relate to disturbances in comparatively small parts of the Sun, but abnormalities shown by average sunlight, as observed when the slit is illuminated by a long strip of an imperfectly focused solar image. In that case, according to Doppler's principle, we may, of course, expect displacements of the lines in consequence of the Sun's rotation, the rotation of the Earth, and the change in the distance between Sun and Earth caused by the eccentricity of the Earth's orbit. But even when all these influences have been allowed for, some irregularities still remain.

Indeed, Jewell has observed that while some Fraunhofer lines exactly coincide with the emission lines in the arc spectrum of elements, others do not, and that the displacements are unequal both for lines of different elements and for the various lines of one and the same element. Moreover, the shifting of certain lines on one set of photographic plates was sometimes found to be different from that on a set of plates taken at another time. With several lines the intensity also appeared to be variable.

Jewell explains these phenomena on certain hypotheses as to

[1] Communicated to the Royal Academy of Sciences, Amsterdam, at the meeting of February 28, 1903.

[2] L. E. Jewell, "The Coincidence of Solar and Metallic Lines: A Study of the Appearance of Lines in the Spectra of the Electric Arc and the Sun," Astrophysical Journal, 3, 89–113, 1896; "Spectroscopic Notes: Absolute Wave-Lengths, Spectroscopic Determinations of Motions in the Line of Sight, and Other Related Subjects," *ibid.*, 11, 234–240, 1900.

density, pressure, and temperature of the absorbing and emitting gases in the different layers of the solar atmosphere, and by variable ascending and descending velocities of matter.

HALE'S ABNORMAL SOLAR SPECTRUM.

Much greater irregularities than those mentioned are found in an "abnormal" solar spectrum, lately described by G. E. Hale.[1]

This highly remarkable spectrum was accidentally photographed as long ago as February, 1894, in a series of exposures, made with the sole intention of investigating the peculiarities of the grating. Only a few months later it was discovered that a very extraordinary phenomenon had been photographed. Hale hesitated to publish this accidental discovery. Copies of the plate were sent to several spectroscopists for examination, with the request that an explanation referring the phenomenon to some origin other than solar be supplied, if possible. As no such explanation was forthcoming, the spectra were very carefully measured and described.

On one and the same plate twelve exposures had been successfully made in the third-order spectrum of a plane grating. A solar image 51 mm. in diameter was so adjusted that the image of a spot fell exactly on the slit. The length of the slit (6.5 mm) corresponded to about one-eighth of the Sun's diameter.

The first exposures show the normal spectrum without any considerable changes. Then came the disturbance which culminated in the eighth spectrum, and in the following four decreased rapidly. Hale gives reproductions of four spectra, each of them extending from λ 3812 to λ 4132. No. 1 was taken before the disturbance occurred; No. 2 is the most abnormal spectrum; No. 3 is called by Hale the "intermediate" spectrum; it was obtained a few moments after the abnormal one; No. 4 shows once more the normal solar spectrum, as it was photographed at another time on another plate. Nos. 1, 2, and 3

[1] "Solar Research at the Yerkes Observatory," ASTROPHYSICAL JOURNAL, 16, 211–233, 1902.

show a dark band throughout the whole spectrum, corresponding to the Sun-spot which had been focused on the slit.

The most prominent features of the abnormal spectrum are:

1. The band due to the spot appears much fainter than in the spectra photographed before and after the disturbance.

2. In the case of several Fraunhofer lines the intensity or the width is *greatly diminished.* This is most conspicuous with the broad, dark calcium bands H and K and with the hydrogen line $H\delta$, these being almost totally absent in the abnormal spectrum.

3. Other Fraunhofer lines, on the contrary, appear *uncommonly strengthened.*

4. Many lines are more or less displaced.

The same peculiarities are noticed, though generally in a lesser degree, in the intermediate spectrum, so that the latter, in fact, forms a link between the abnormal and the normal spectrum.

This marvelously complicated disturbance was not confined to light coming from a comparatively small part of the solar disk, for instance from the immediate surroundings of a spot; on the contrary, it extended almost equally over the whole width of the spectrum and was therefore nearly the same for all the light which came from a very great area of the Sun.

The moments of the twelve exposures and the exact date had not been recorded; but there was sufficient evidence that the whole process of the disturbance lasted only a very short time. Hale calls the phenomenon "a remarkable disturbance of the reversing layer." But is it not almost impossible to imagine a rather thin layer in the solar atmosphere undergoing suddenly and simultaneously over a great part of the Sun a change so great as to make its absorbing and radiating power in some parts of the spectrum for a while nearly unrecognizable?

It occurred to me, therefore, that the origin of the phenomenon should be looked for somewhere on the path of the light between the Sun and the Earth. If on this path there be media causing anomalous dispersion, the beam must show an altered composition.

As I formerly indicated,[1] the properties of the chromospheric light may be derived from the supposition that this light has been separated from the photospheric light by anomalous dispersion. According to this hypothesis the spectrum of the chromosphere informs us which are the kinds of light that may follow rather strongly curved paths in the solar atmosphere. So the idea suggested itself that the same waves might play a striking part in Hale's abnormal spectrum.

In order to investigate the question as impartially as possible, I marked (before consulting Hale's table or a table of chromospheric lines) on the reproductions of the spectra in the ASTROPHYSICAL JOURNAL a number of lines which struck me as being *weakened* in the abnormal spectrum. By means of George Higgs' photographic atlas of the normal solar spectrum the wave-lengths of the selected lines were easily read. They are to be found in the first column of Table I.

The second, third, and fourth columns show the intensities of these lines in the normal, the intermediate, and the abnormal spectrum as given by Hale (for the normal spectrum from Rowland's tables, for the other two from estimates by Mr. Adams). Hale remarks that the intensities of the lines were estimated independently for the two disturbed spectra.[2] The fifth column indicates the intensities of corresponding chromospheric lines as found by Lockyer in the spectrum secured at Visiadrug[3] during the 1898 eclipse; the sixth column shows the absorbing substances.

Table II has been prepared in a similar way; here we find the lines, which on the reproduction appeared to be *strengthened* in the abnormal spectrum.

[1] ASTROPHYSICAL JOURNAL, **12**, 185–200; **15**, 28–37; *Physikalische Zeitschrift*, **4**, 85–90; 132–136.

[2] In selecting the lines that appeared weakened in the abnormal spectrum, I of course compared the three spectra together. That is why in my table some lines occur whose intensities as estimated by Mr. Adams are not comparatively low in the abnormal spectrum.

[3] LOCKYER, CHRISHOLM-BATTEN, AND PEDLER, "Total Eclipse of the Sun, January 22, 1898.—Observations at Visiadrug," *Phil. Trans.*, A, **197**, 151–227, 1901.

TABLE I.

LINES WHOSE INTENSITY IS LESS IN THE ABNORMAL THAN IN THE NORMAL SPECTRUM.

WAVE-LENGTH	INTENSITY				ELEMENTS	REMARKS
	Normal (Rowland)	Intermediate (Hale)	Abnormal (Hale)	Chromosphere (Lockyer)		
3871.4				4	*C*	Not mentioned in Hale's list, but distinctly weakened in the abnormal spectrum on reproduction.
3872.6				4	*Fe*	
3874.09	4	9	..	2 (?)	*Fe*	
3878.47	22	25	..	3–3	*Fe*, *Fe*	λ = 3878.15 and λ = 3878.72. Hale mentions *Fe*, *Mn*.
*H*ζ 3889.05	?	15	..	8	*H*	
3895.80	7	12	..	3	*Fe*	
3899.30	5	4	..	2	*V?*	
3903.09	10	12	..	2–3	*Fe*	
3905.66	12	20	..	2	*Cr*, *Si*	
3906.70	14	..	4	2	*Fe*	
3913.63	9	7	..	6	*Ti*	
3914.49	7	8	5*		*Ti*	* These intensities are very probably estimated too high when compared with the numbers in the second column. *Cf.* note 2 on p. 53.
3916.54	3	..	4*	3	*V*	
3920.41	10	10*	10*	3	*Fe*	
3923.05	12	12*	12*	3	*Fe*	
K 3933.82				10	*Ca*	
3944.16	15	15*	12*	5	*Al*	
3948.91	13	15	..	3	*Fe*	
3950.10	5	..	2	3	*Fe*	
3953.02	17	15	..		*Fe*, etc.	
3958.35	5	8	..	4	*Ti*	
3961.67	20	20	..	6	*Al*	
H 3968.63	(700)	7	7	10	*Ca*	
*H*ε 3970.18	7	8	..	10	*H*	
3977.89	6	8	..	2	*Fe*	
3986.90	6	8	..		....	
3998.78	4	4	4*	4	*Ti*	
4012.50	5	4	5*	5–6	*Ti*, etc.	
4033.22	7	12	3	3–4	*Mn*, *Fe*	
4034.64	6	10	..	3–4	*Mn*, *Fe*	
4045.98	30	30	5	7	*Fe*	
4063.76	20	20	..	6–7	*Fe*	
4071.91	15	15	15*	6	*Fe*	
4077.88	8	10	7*	10	*Sr*	
*H*δ 4102.00	40	7	..	10	*H*	

The result is very striking. *Weakened lines correspond to chromospheric lines almost without exception; most of the strengthened lines, on the other hand, are not to be found in the spectrum of the chromosphere.*

Lockyer gives the strength of the chromospheric lines on a scale such that 10 indicates the strongest and 1 the faintest lines. If we take into account that in his list the greater part of

TABLE II.

LINES WHOSE INTENSITY IS GREATER IN THE ABNORMAL THAN IN THE NORMAL SPECTRUM.

Wave-Length	Intensity				Elements	Remarks
	Normal (Rowland)	Intermediate (Hale)	Abnormal (Hale)	Chromosphere (Lockyer)		
3921.86	4	..	20		*Zr, Mn*	
3927.77	..	..	25		?	
3930.45	8	15	28	3–4	*Fe*	
3937.39	..	..	10		?	
3940.25	..	7	12		?	
3950.50	2	..	13		*Y*	
3962.29	3	..	11		*Fe ?*	
3973.77	6	..	15	2 (?)	*NiZrFeCa*	
3981.92	4	13	30	6*	*Ti, Fe*	* In Humphreys' table of chromospheric lines (1901 eclipse) this line does *not* occur.
3992.97	3	4	10		*V, Cr*	
3996.80	..	..	9		?	
4013.90	8	12	15		*Ti, Fe*	
4014.67	5	9	20		*Fe*	
4023.38	..	..	10		?	
4033.77	2	3	15		*Mn*	
4040.79	3	6	20	4	*Fe*	
4044.09	5	20	15		*Fe*	

the lines bear the numbers 1 and 2, our table shows us that by merely observing the abnormal solar spectrum we have been able to pick out *strong* chromospheric lines. This cannot be chance. Undoubtedly both phenomena—the weakening of Fraunhofer lines in the abnormal spectrum and the origin of the chromospheric spectrum—are to be explained in close relationship with each other.

The *strengthening* of lines in the abnormal spectrum does not, on the contrary, seem to be so directly connected with the composition of the chromospheric spectrum.

If our view be correct that the chromospheric light has been separated by strong ray-curving from the "white" light emitted by deeper layers, those special radiations must, as a rule, show reduced intensity in the spectrum of the Sun's disk.[1] Fraun-

[1] It might be thought that the rays forming the chromospheric light need to be absent only from the spectrum of the *edge*, but not from that of the central portions of the Sun's disk. By a simple consideration following from a glance at Fig. 4 of my paper read in February, 1900 (ASTROPHYSICAL JOURNAL, **12**, 191), we see, however, that the chromospheric light visible to us may very well, in part, have its origin even

hofer lines corresponding to chromospheric lines will therefore have a more or less darkened background in the ordinary solar spectrum. The rate of darkening at various distances from the center of an absorption line is, of course, connected with the shape of the dispersion curve near that line; whereas the average shading depends also (1) on the quantity of matter causing anomalous dispersion and (2) on the slopes and directions of the density gradients in the gases through which the light is transmitted, viz., on the Sun's "activity."[1]

We distinguish, therefore, a twofold origin of the dark lines in the solar spectrum, viz.: real *absorption* of those waves which exactly correspond to the periods of the media and *dispersion* of the strongly deviated[2] neighboring light.

The dispersion will be especially evident where extraordinary differences in the density of the medium occur; in this way the widening of most of the Fraunhofer lines in the spectra of spots may be accounted for.

Dispersed light has not, of course, vanished; the absence of certain rays in the spectrum of a spot is counterbalanced by the increased intensity of the same radiations in the light coming from the neighboring faculæ. Thus the distribution of the density in the solar gases may locally be such that a limited part of the disk seems to emit a considerable amount of rays with abnormally high or abnormally low refractive indices. In the spectrum of this part not only will the Fraunhofer lines appear

in points of the Sun which lie opposite to the Earth's direction. The chromospheric light reaching the Earth may proceed from *any* point of Schmidt's "critical sphere." For the greater part it is likely to come from the back half of the Sun. But then the half facing us furnishes the chromospheric light which travels to other regions of the universe, and this light, of course, is wanting in the spectrum of the disk. There is some reason for supposing that, on an average, more chromospheric light is sent forth in directions making great angles with the Sun's equator than to the equatorial regions, including the Earth's orbit.

[1] The possible influence of the general or regular ray-curving (on Schmidt's principle) on the appearance of the spectral lines has in the present paper been left out of consideration. If we were able to observe or to calculate the radii of the "critical spheres" for radiations undergoing anomalous refraction, it would be possible to estimate that influence; but as yet sufficient data are wanting.

[2] ASTROPHYSICAL JOURNAL, **12**, 191, 1900.

narrower and fainter than usually, but we may even meet with lines contrasting *brightly* with their surroundings. These bright lines will not coincide with the corresponding absorption lines; their average wave-length will in general be greater or smaller than that of the absorbed light, for, according to the accidental distribution of the density, we shall find either the rays with high or those with low refractive indices most prominent in the beam.

The above considerations suggest an explanation of Hale's abnormal spectrum. In fact, the lines showing especially faint in this spectrum were exactly those which cause strong anomalous dispersion—witness the chromospheric spectrum. With H, K, $H\delta$, and some iron lines it is very evident that the abnormal faintness refers mainly to the broad dark shadings of the lines, *i. e.*, those parts whose darkness in the normal spectrum we attributed, not to absorption, but to dispersion. Moreover, the dark band due to the spot has nearly disappeared. This means that waves, which in normal circumstances are wanting in the spot spectrum on account of their strong dispersion, at the time of the disturbance had been gathered again into the beam, reaching the instrument. How all this may happen will become evident as soon as we shall be able to establish a plausible cause by which, within an angular space great enough to include a considerable part of the solar disk, the *strongly dispersed rays might be gathered again.*

It is not necessary to introduce a new hypothesis for the purpose. The same idea about the Sun's constitution which enabled us to explain the properties of the chromosphere and the prominences[1] furnishes us once more with the required data. Indeed, if (according to Schmidt's theory) the Sun is an unlimited mass of gas, surfaces of discontinuity must exist similar to those whose general feature has been determined by Emden[2] for a sharply outlined radiating and rotating Sun. These surfaces must extend to the remotest parts of the gaseous body—a conclusion in excellent harmony with the visible structure of the corona. For along the surfaces of discontinuity waves and whirls are formed; the core-lines of the vortices nearly coincide

[1] *Physikalische Zeitschrift*, **4**, 85–90. [2] ASTROPHYSICAL JOURNAL, **15**, 38–59, 1901.

with the generatrices of the surfaces of revolution, and in these cores the density is a minimum. This may account for the streaky appearance shown more or less distinctly in all good photographs and drawings of the corona.

This particular appearance may have another cause, however, but for what follows this is immaterial. We only assume that the density of the coronal matter varies in such a way as to correspond to the striped structure visible at the time of a total eclipse of the Sun.

A coronal streamer which at a given moment runs exactly in the direction of the Earth may be very roughly compared, then, to a bundle of glass tubes through which we are looking lengthwise. Such a structure will gather and conduct rays of various directions, entering it at one end. This takes place also if the parts with the greater and those with the smaller optical density do not alternate abruptly, but gradually.

In Fig. 1 the optical density of the matter may be represented by the compactness of the streaking. A ray for which the medium has a large positive refraction constant would, for instance, follow the path AA', curving round the denser parts of the structure; a ray BB', for which the medium possesses a large negative refraction constant, would move in a similar way through the more rarefied regions. On the other hand, the light CC' for which the constant exactly equals zero is not influenced by the fluctuations of the density; and if for some kind of light the refraction constant is very nearly zero, the ray would have to travel a long way almost parallel to the structure before its curving would be perceptible.

Now the corona sometimes shows exceedingly long, pointed streamers. We only have to suppose *that the Earth was exactly in the direction of such a streamer at the moment the abnormal spectrum was photographed;* then all the irregularities observed in this spectrum become clear. Light under normal circumstances absent from the solar spectrum through strong dispersion has been collected by the coronal streamer; hence the *weakening* of the Fraunhofer lines, especially, also, of those in the spectrum of the spot. As the abnormalities were caused by a peculiar distribution of matter in the vast regions of the corona lying between the source of light and the Earth (and not by disturbances in a relatively thin "reversing layer"), they could appear in the same way over a great part of the Sun's disk. The *rarity* of the phenomenon is the result of the slight chance we have to take a photograph at the very moment on which an uncommonly long coronal streamer is projected exactly on the part of the Sun's disk illuminating the slit; finally, the *short duration* is a consequence of the Earth's orbital motion, and probably of the rotation of the corona.

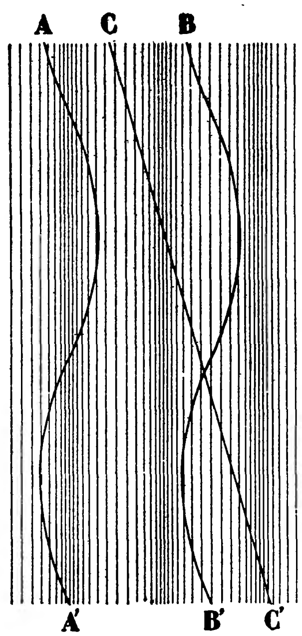

FIG. 1.

As we have mentioned before, *no* chromospheric lines correspond, in general, to those lines appearing extraordinarily *strong* in the abnormal spectrum. How are we to account for the strengthening of these lines?

We might be tempted to think of absorption in the corona; for if it be true that a streamer was turned toward the Earth, the rays had to go an uncommonly long way through an absorbing medium. But on closer examination this idea is less probable.

The particles of the extremely rarefied coronal gases will hardly influence each other; their periods will, therefore, be almost absolutely constant, so as to cause very sharp, narrow absorption lines. Thus it is difficult to understand how an absorption line already present in the normal solar spectrum might be strengthened by the absorbing power of the corona. Further, in studying Hale's table, we observe that many lines which are strong in the abnormal spectrum show a much smaller intensity in the intermediate spectrum (taken only a few moments later); while the reverse happens as well, viz., that lines are strong in the intermediate and very weak in the abnormal spectrum. This hardly fits in with the absorption hypothesis. Some lines showing this peculiarity are given in Table III:

TABLE III.

LINES WHOSE INTENSITY IS VERY DIFFERENT IN THE INTERMEDIATE AND THE ABNORMAL SPECTRUM.

WAVE-LENGTH	INTENSITY				ELEMENTS	REMARKS
	Normal (Rowland)	Intermediate (Hale)	Abnormal (Hale)	Chromosphere (Lockyer)		
3905.66	12	20	..	2	*Cr, Si*	
3905.81	21	..	20		*Si*	
3921.71	9	14	..		*Ti, La, Zr, Mn*	
3921.87	4	..	20		*Zr, Mn*	
3950 33	..	10	..		?	
3950.51	2	..	13		*Y*	
3972.30	2	12	..		*Ni*	
3972.61	2	..	12		?	
4005.86	3	25	5		?	
4057.39	4	..	15	1–2	*Co, Fe*	
4957.66	7	10	..		?	

In the chromospheric spectrum corresponding lines seem to be wanting (at λ 3905.66 and λ 4057.39 the faint chromospheric line may possibly belong to another element than the abnormally strengthened absorption line).

To arrive at a more satisfactory explanation of the strengthening phenomenon, we suppose that these absorption lines do indeed cause anomalous dispersion of neighboring waves, but in a very slight degree. Then, the refractive indices of the neighboring waves differing but little from unity, the direction of those rays will be perceptibly changed only after they have traveled a very long way through the corona and almost parallel to its structure lines. Whereas the strongly refracted rays, entering the coronal streamer in various directions, were obliged to follow the structure lines, curving about them, and so in a sense were concentrated on the Earth, it may happen with the very slightly curved rays we are now considering that they have been bent, for instance, only once over the whole length of the streamer and continue their way in a direction not meeting the observing station. The divergence of a beam consisting of these rays will have increased, the intensity diminished. Thus the resultant spreading of neighboring light causes the absorption line to appear somewhat widened, and therefore strengthened. But obviously it must be possible, too, that after a short time, under the influence of another part of the corona, circumstances assist that slightly curved light to reach the observer. In that case the absorption line is weak again. (Similar alternations, of course, also occur with the more strongly refracted rays, and that in quicker succession; but this does not alter the fact of their *average* intensity appearing increased as long as the structure lines of the coronal streamer are turned toward the spectroscope. For a detailed discussion of this case see the note at the end of this paper.)

In both abnormal spectra a number of absorption lines are more or less displaced. Perhaps this is partly due to motion in the line of sight, but after the foregoing it will not be necessary to explain in detail that anomalous dispersion also can account for this phenomenon. Dissymmetric form of the dispersion curve as well as a peculiar distribution of the density of the coronal matter may unequally affect the intensity of the light on both sides of the absorption line, and thus bring about a seeming displacement of the line.

CERTAIN PECULIARITIES OF LINES IN THE NORMAL SOLAR SPECTRUM.

If we have been right in connecting the uncommonly great abnormalities in Hale's spectrum with a very particular position of the Earth with respect to the corona, it is to be expected that similar irregularities, though in less degree, will continually be found, as the sunlight always reaches us through the corona.

According to Jewell's above-mentioned investigations, this supposition proves to be well founded. Many solar lines have varying intensities and positions, so that Jewell deems them unfit for standards for very accurate determinations of wave-lengths. And these are for the greater part the most prominent lines of the spectrum, especially the shaded ones.[1]

Jewell emphasizes the fact that all distinctly shaded lines in the solar spectrum show to a greater or less degree the following

[1] ASTROPHYSICAL JOURNAL, 11, 236, 1900.

typical feature:[1] With a broad, shaded, moderately dark background a much darker central absorption line contrasts rather sharply (Fig. 2). Besides, the absorption curve often shows depressions close to the central line, as in Fig. 3, sometimes symmetrical, sometimes dissymmetrical. Jewell affirms that this is not an optical delusion, due to contrast, but a real phenomenon. He assumes, therefore, that the broad absorption band is produced in the lower portions of the solar atmosphere and under a great range of pressure; that in higher levels radiation prevails again, producing a rather wide emission line; and that finally in the highest parts, where the pressure is very much less, the sharp absorption line is produced. The position of this central absorption line with respect to the emission line is usually unsymmetrical, which is conspicuous in the case of H and K. The central line itself also varies somewhat in width upon different plates, and its maximum of intensity is not always in the middle of the line. The displacement of this central line in H and K varies in magnitude, but, so far as has been observed, always toward the red with respect to the emission line and the corresponding metallic line (in the arc). Jewell concludes that the absorbing calcium vapor descends all over the solar surface with a velocity sometimes amounting to about seventy-five miles per minute.

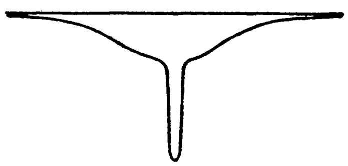

Fig. 2

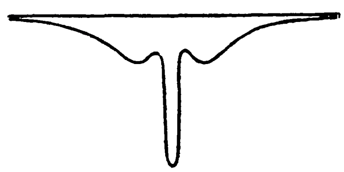

Fig. 3.

Upon the same plates showing strong dissymmetry in H and K the shaded lines of other elements (*Fe*, *Al*, *Mg*, *Si*) have been examined. The strongest iron lines and one aluminum line showed displacements of the same character as that observed in the case of H and K, but to a much smaller degree, and sometimes toward the violet, sometimes toward the red. Certain

[1] "Certain Peculiarities in the Appearance of Lines in the Solar Spectrum and Their Interpretation," *Ibid.*, 3, 1896.

shaded lines of *Mg* and *Si*, on the contrary, showed no evidence of a displacement, nor did the iron lines without considerable shading, the faint calcium line at λ 3949,056, and many other lines.

If we admit no other explanation of line-shifting and widening besides those based on Doppler's principle and on the effect of pressure and temperature, we arrive at very strange conclusions with regard to the condition of the elements in the solar atmosphere. Not less surprising, as noticed by Jewell,[1] is the small amount of the absorption in the shaded parts of the lines, when we consider the enormous depth of the solar atmosphere and the high pressure which must exist in the absorbing layers for them to produce a broad absorption band.

By making various suppositions concerning the condition of the gases in the solar atmosphere, Jewell succeeds in finding an interpretation of most of these astonishing facts. But it must be granted that his explanations include a greater number of arbitrary and mutually independent hypotheses than is the case with our explanations, founded as they are on selective ray-curving and readily deduced from that principle for each separate phenomenon, without introducing new suppositions.

Only the dark central lines of the Fraunhofer lines are to be ascribed, in our theory, to real absorption. Their shaded background of varying intensity we consider as an effect of anomalous dispersion of the not absorbed neighboring waves. This selective scattering will be strongest in those places where the density-gradients are relatively steep, viz., in whirls in the deeper regions of the gaseous body. But some of the widely dispersed rays may be gathered by the corona owing to its "tubular" structure, and be conducted along its greater or smaller streamers. This will especially apply to the most strongly refracted waves, whose position in the spectrum is very close to the real absorption lines; thus pseudo-emission lines are produced in about the middle of the pseudo-absorption bands.[2]

[1] ASTROPHYSICAL JOURNAL, 3, 106, 1896.

[2] A most remarkable fact is that the shading of H, K, the iron line λ 3720.086 and of some other strong shaded lines is sometimes partially broken up in a series of faint

Probably Hale's abnormal spectrum has shown us a case where these seeming emission bands acquired an uncommon extent. We may therefore expect that a systematical investigation of solar spectra, photographed at different times, will afford all kinds of intermediate cases.

It would be desirable, for the moments when the photographs are taken, to know the form and position of the coronal streamers directed toward the Earth. At all events the actual phase of the Sun-spot period, with which the shape of the corona seems to be connected, should be taken into consideration ; and perhaps the simultaneous observation of the photospheric reticulation discovered by Janssen may procure some evidence concerning the position of coronal streamers, and thus contribute to our knowledge of their influence on the Fraunhofer spectrum.

UTRECHT, April 7, 1903.

nebulous lines, symmetrically situated about the central line (JEWELL, ASTROPHYSICAL Journal, 3, 108, 1896). It might have been predicted by our theory that we should meet with this phenomenon. Let us consider a beam of light of an exactly defined wave-length belonging to the shaded background of an absorption line. This beam leaves the deeper layers of the Sun with a certain divergence. As it passes along a "tube" of the corona, its divergence will alternately diminish and increase, and on reaching the Earth it shows in the spectrum an intensity depending on the divergence (or, perhaps, convergence) with which it has left the last traces of the corona. For a beam of light whose wave-length is only slightly nearer to that of the absorption line, the medium will have a considerably greater refraction-constant, so that the rays of this beam on their way through the corona may make part of a bend more than the former ones. The beam may therefore arrive with a quite different degree of divergence, and, consequently, of intensity. Thus, proceeding toward the absorption line from either side, we easily see that we must meet with a periodically changing intensity. Rays corresponding to the middle of one of the fringes so formed will have made one full bend more or less than the rays belonging to the middle of the next fringes.

If this interpretation be correct, the width and the number of fringes visible must prove to be variable. So far as I know, the observations made on this point are not numerous. I trust that the proposed views may serve to further the investigation of this interesting phenomenon.