Citation:

W.H. Julius, Spectroheliographic results explained by anomalous dispersion, in:
KNAW, Proceedings, 7, 1904-1905, Amsterdam, 1905, pp. 140-147

times, when passing nearly parallel to the system of the levels of equal density (in the manner described on a former occasion [1])) and will therefore have a greater chance of reaching the slit S_2, than rays which are less strongly curved. The relative intensity with which the waves, belonging to those central parts of the dispersion bands, appear in the spectrum increases with the distance over which the light has travelled along such a lamellar or tubular structure. Should the true absorption line happen to be exceedingly narrow, the dispersion band may give the impression of a double absorption band, which need not be symmetrical [2]).

We hold that the dispersion bands play an important part in many of the well known spectral phenomena, such as the widening, shifting, reversal and doubling of lines. In a subsequent communication I purpose to examine from this premise various phenomena observed in the spectra of variable stars and other celestial bodies.

Physics. — "*Spectroheliographic results explained by anomalous dispersion.*" By Prof. W. H. Julius.

It is not surprising that the scientific world should be highly interested in the beautiful results, obtained by Hale and Ellerman with the spectroheliograph [3]). The brilliant method elaborated and applied by these investigators enables us to see at a glance as well as to study in minute details how the light of any selected wavelength was distributed on the total solar disk at any given moment. W. S. Lockyer, in giving an abstract from the paper here alluded to in Nature N°. 1800, rightly entitles it: "A new epoch in solar physics." Indeed, the spectroheliograph proves capable of providing us with an abundance of new information, which other existing methods could never give and the value of which will remain, whatever may be the ideas on the Sun's constitution derived from it.

But, nevertheless, even the most splendid collection of new facts is useless so long as we have no theoretical ideas connecting them with achieved knowledge. Hale and Ellerman, accordingly, in

1) Proc. Roy. Acad. Amst. IV, p. 596.

2) In Fig. 4 on the plate is given an enlargement of one of the photographs obtained by an almost symmetrical position of the flame. It has been somewhat spoiled in the reproduction. The original is less blotchy and the transition of the dispersion bands to the bright background of the spectrum is there much more gradual.

3) G. E. Hale and F. Ellerman, "The Rumford Spectroheliograph of the Yerkes Observatory," Publications of the Yerkes Observatory, Vol. III. Part. I, (1903).

describing the observed phenomena, lay down quite definite conceptions regarding certain conditions and configurations of matter in the solar atmosphere, by which the observed distribution of the light in the image of the Sun is assumed to be produced. In the cited publication they put forth the working hypothesis that the "calcium-flocculi" or bright regions showing themselves all over the image of the Sun when it is photographed in so-called calcium light, are columns of calcium vapour rising above the columns of condensed vapours of which the photospheric "grains" are the summits (l.c., p. 15). This hypothesis, though at first proposed mainly as a guide to further research (l.c., p. 13), has been subsequently[1]) employed by the same authors with much less restriction as the basis on which the photographs ought to be interpreted.

The great authority of HALE and of such critics as W. S. LOCKYER, J. EVERSHED and others who, in abstracts from the work of HALE and ELLERMAN, concur in most of the interpretations there given, might cause the value of those ideas to become overestimated and extended beyond the original intention of the authors.

It is not superfluous, therefore, to show how we may quite as well account for all the new phenomena thus far revealed by the spectroheliograph, if we start from the entirely different conceptions of the Sun's constitution, which the consequences of ray-curving in non homogeneous media and of anomalous dispersion of light in absorbing vapours have suggested to us.

Both these circumstances are left absolutely out of consideration by HALE and ELLERMAN. Their conclusions are all founded on the erroneous supposition that the monochromatic light by which their images of the Sun are photographed, has travelled from the source in straight lines, and that they are right, accordingly, in supposing light-emitting masses of calcium vapour to exist in the exact directions, along which calcium-radiations seem to reach us. In making this supposition they fall into the same error as one who would assume the refracting facets of the crystal globe of a burning lamp to be independent sources of light.

Our new explanation of the spectroheliographic results will be founded on the hypothesis that the Sun is an unlimited mass of gas in which convection currents, surfaces of discontinuity and vortices are continually forming under the influence of radiation and rotation, so that the various composing elements are mingled as completely as nitrogen

[1]) G. E. HALE and F. ELLERMAN, "Calcium and Hydrogen Flocculi," Astrophysical Journal XIX, p. 41—52.

and oxygen in the Earth's atmosphere [1]). This hypothesis too will, of course, want modification in the light of future results; but for the present it seems, so far as the visible phenomena are considered, not to clash with any observation or physical law.

The irregular motion of electrons in the deeper layers of the Sun, where the density is very great, gives rise to the radiation with a continuous spectrum. We shall only take *this* radiation into account. Peculiar radiations, emitted by the more rarefied outer parts of the gaseous body and giving a bright-line spectrum, may perhaps add a perceptible quantity of light to the bulk, but this selective emission, if present, does not play any part in our explanations. So we behold the brilliant core of the Sun through an extensive envelope, consisting of a transparent but selectively absorbing mixture of gases, into which the core gradually spreads. It stands to reason that the average density of this envelope slowly decreases in the direction from Sun to Earth; but at right angles to that direction the density must be in some places much more variable. For it is a minimum in the axes of vortices; and the average direction of the whirl-cores, lying between the Earth and the central parts of the Sun in the surfaces of discontinuity, differs but little from our line of sight. The rays of the Sun thus reach us after having travelled a great distance along lines, making small angles with the levels of slowest density-variation in a lamellar, partly tubular, structure [2]).

Under these circumstances the solar rays will be sensibly incurvated on their way through the envelope, especially those suffering anomalous dispersion. As a rule, beams consisting of the latter kinds of rays will show an increased divergence; they will reach the Earth with less intensity than the normally refracted light and so will give rise to dark *dispersion bands* [3]) in the solar spectrum. And the degree of divergence will not only be different with waves, which in the spectrum are found at different distances from the absorption lines, but it is also clear that the divergence with which various beams of *any definite* kind of light arrive at the Earth must differ largely according to the dioptrical properties, exhibited along the

1) A sketch of a solar theory, based on this hypothesis, is to be found in the Revue générale des Sciences, 15, p. 480—495, 30 May 1904.

2) For considerations which have induced us to hold that a similar structure of the Sun is very probable, I refer to former publications: Proc. Roy. Acad Amst. IV, p. 162—171; 589—602; V, p. 270—302.

3) W. H. Julius, Dispersion bands in absorption spectra, Proc. Roy. Acad. at Amst. Vol. VII, p. 134.

paths of those beams by the system of surfaces of discontinuity.

The foregoing inferences really imply the whole of our interpretation of the results, thus far obtained with the spectroheliograph. This we shall show by amply discussing some of their main features.

The broad dark bands, designated by HALE and ELLERMAN as H_1 and K_1, are not absorption bands, but dispersion bands. Real absorption by the solar calcium vapour we hold to be restricted to the central dark lines H_3 and K_3. The bright bands H_2 and K_2, predominating in the spectrum of the "flocculi" and attributed by HALE and ELLERMAN to strongly radiating calcium vapour, result in our theory from the fact, that with beams of light the wavelength of which is very near to that of the central absorption lines, the divergence may be diminished or even changed to convergence by the tubular structure. Indeed, such rays deviate more strongly than those standing farther from the absorption lines; and as soon as they undergo more than one incurvation, they have a chance of reaching the Earth with increased intensity. This chance improves in proportion as the index of refraction departs from unity, be it in a positive or in a negative sense[3]). We conclude from it, that the brightness of the calcium flocculi must, as a rule, increase as the monochromatic light in which the Sun is photographed approaches the true absorption line.

This consequence of our theory exactly corresponds to one of the chief peculiarities, which immediately struck HALE and ELLERMAN on inspecting sets of photographs taken at short intervals of time with the second slit in different positions within the H and K bands. In order to account for the same fact, those investigators are obliged, by their working hypothesis, to suppose that in higher regions of the Sun's atmosphere the calcium vapour radiates more strongly than in lower levels. This cannot be called a very satisfactory inference; and less so, as the supposition is added that the incandescent vapour is rising from much deeper layers and, therefore, considerably expanding — a process during which, according to our physical notions, the temperature must fall. Here we meet with a serious difficulty; HALE and ELLEMAN try to get rid of it by means of the rather vague assumption, that some electrical or chemical effect may be responsible for the bright radiation emitted by this calcium layer, which is intermediate between two absorbing layers[2]).

[3]) In the experimental investigation on dispersion bands, before mentioned, this brightening in the middle of the dark bands has been distinctly observed. Cf. also: Proc. Roy. Acad. Amst. Vol. IV, p. 596.

[2]) HALE and ELLERMAN, Astrophysical Journal XIX, p. 44.

Our theory can dispense with such additional hypotheses.

Another characteristic peculiarity, observed in every series of photographs taken at short intervals with the slit set at various points on the broad H and K bands, is the following. When the slit is set, e.g., at a remote point of K_1, the structure of the solar image appears relatively fine, sharp and detailed; approaching the central line, we see some of the brilliant spots vanish, others grow more extensive, especially those lying in the vicinity of sun-spots; at the same time their outlines become less sharp, so that finally the whole image gives us the impression of a coarser and at the same time a more woolly structure [1]).

HALE and ELLERMAN hold that the successive photographs refer to gradually higher levels and conclude that the masses of calcium vapour must have a tree-like shape. W. S. LOCKYER, in Natur No. 1800, draws a scheme showing this conception.

Against this interpretation we propose the following one.

The amount by which the divergence of a beam of light is altered in consequence of the presence of calcium vapour in the streaming and whirling mass depends, of course, on the proportion of calcium in the mixture, and besides on two other circumstances, viz. 1st on the position occupied in the spectrum by the selected kind of light with regard to the absorption lines, and 2nd on the steepness of the density gradients in the mixture along directions perpendicular to the path of the beam.

Let us suppose the selected light to correspond to the extreme edge of H_1 or K_1, then its index of refraction differs but little from unity. Accordingly, very considerable inequalities of density are required to cause a perceptible change in the divergence of such beams. Similar great inequalities may indeed occur at many separate places, but at each of them they cannot, of course, extend very widely. This accounts for the fine and rather sharply defined reticulation shown by the so called "low-level" photographs.

If the second slit were set a little nearer to the centre of the line, the distribution of the light in the solar image would at all events differ considerably from that of the former case; for the indices of refraction being very different for neighbouring waves within a dispersion band, the divergence of beams, starting from the same point of the Sun, must vary largely with the wave-length. So it is clear

---

[1]) Such series of photographs are reproduced in: Publications of the Yerkes Obervatory, Vol. III, Part I, Pl. V, VI, X, XI, XII, XIII.

that bright or dark spots, visible on one photograph, may be wanting in the other.

Moreover, the general character of the image must change as we approach the central line. For in proportion as the indices of refraction depart from unity, slower variations of density suffice for producing sensible differences of divergence. And, as a matter of course, in any whirling region slightly inclined density-gradients will take up larger spaces than very steep ones. Besides, when the second slit of the spectroheliograph, having a given width, is set near to the central absorption line, the wave-complex which it allows to pass, covers a greater variety of refractive indices, than when it is set farther from the central line. In the former case the distribution of the light in the solar image must, therefore, be less differentiated. Both circumstances cooperate in causing the bright-and-dark structure generally to appear coarser and more woolly in proportion as the spectroheliograph is adjusted for kinds of rays that are more liable to anomalous dispersion.

From the same point of view it is not surprising that on photographs, taken in H_2 or K_2 light, the calcium flocculi are particularly bright and extensive in spot regions, for in such regions the "tubular" structure of the gaseous mass, by which the strongly curved rays are kept together and conducted, is most developed.

HALE and ELLERMANN also mention "dark calcium flocculi" [1]), which they describe as special objects, visible in so-called "high-level photographs" and not to be confounded with the general dark background, produced by the absorbing calcium vapour of deeper layers. Dark flocculi often surround the large bright flocculi of spot regions, as is shown e.g. in Fig. 4, Plate V of the cited publication. The explanation given by them is, that we might have here some indications of the cooler K_3 calcium vapour, which rises to a considerably greater height than the K_2 vapour of the bright flocculi.

In our theory the presence of these darker regions is a direct consequence of the fact, that the particular distribution of the light in the solar image is not produced by local absorption and emission, but by irregular ray-curving. The rays are only caused to change their places; so an excess of light in the bright flocculi must necessarily be counterbalanced by a deficit in the surroundings.

H and K are by far the broadest bands of the visible solar spectrum; even with moderate dispersion the second slit of the spectro-

1) Publications Yerkes Observatory, l. c. p. 19.

heliograph could easily be set at different points within these bands. When the dispersion of the instrument was increased by means of a grating, photographs of the Sun could be obtained with light falling entirely within a widened line of hydrogen or of iron.

Photographs made with H_β or H_γ light showed also a flocky structure, differing, however, materially from that obtained with H and K. HALE and ELLERMANN therefore assume dark and bright clouds of hydrogen to exist in the solar atmosphere. Upon the whole, but not in the details, the hydrogen flocculi correspond in form and position to the calcium flocculi photographed with H_2 or K_2 light; the general aspect of the photographs is fainter, they show less contrast, and the detailed structure observed in H_1 or K_1 light is wanting. The most striking fact, however, is that the bright calcium flocculi of the H_2 or K_2 photographs are replaced on the H_β photograph by dark structures of similar form. Only in a few places in the vicinity of sunspots small *bright* hydrogen flocculi occur which coincide with parts of bright calcium flocculi.

HALE and ELLERMAN hardly make an attempt to explain these facts which, in the light of their working hypothesis, are really puzzling.

We get a much clearer view of the matter as soon as we suppose the widening of the hydrogen lines also to be produced by anomalous dispersion, instead of by absorption only.

Indeed, the ray-curving in the solar gases must generally be less with waves belonging to those narrower dispersion bands than with waves lying near the centres of the broad H and K bands. Even in the powerful whirls of spot regions there will only sporadically be found places where the tubular structure is sufficiently marked to keep together rays belonging to the dispersion bands of hydrogen in the same way, as it does gather the strongly curved H_2 and K_2 light in the large, bright calcium flocculi. Accordingly, we shall meet with very few places in bright calcium flocculi, where the photographs in H_β or H_γ light also exhibit brilliant points. All the rest of the bright H_2 and K_2 regions correspond to those parts of the gaseous mass where the differences of density — though not so excessive — are nevertheless very considerable; but whereas in that structure the H_2 rays are repeatedly curved and may be made to converge, the less strongly incurvated H_β rays will in the same regions diverge and be dissipated in a considerable degree, thus giving rise to dark places in the photographs. Outside the bright calcium flocculi, finally, where the H_2 and K_2 photographs are dark in consequence of increased divergence of the beams, no strong incurvation is given to the H_β or H_γ light; at those places the image of the Sun, photographed in hydrogen lines, must therefore be less dark.

The rather faint character of the hydrogen flocculi, the absence of sharp outlines and of strong contrasts in the structural elements, we ascribe to the dispersion bands of hydrogen being relatively narrow and so allowing rays with a great variety of refractive indices to pass simultaneously through the second slit of the spectroheliograph. The hydrogen photographs too would show finer details, like those in K_1 light, if the dispersion of the apparatus were still greater and the second slit still narrower.

We believe that we have shown that every peculiarity, thus far noticed in the photographs obtained with the spectroheliograph, may easily be deduced from the same fundamental hypothesis regarding the constitution of the Sun, which has already proved capable of giving a coherent interpretation of the solar phenomena known before. Not a single new hypothesis was required.

Physiology. — *"On artificial and natural nerve-stimulation and the quantity of energy involved."* By Prof. H. Zwaardemaker.

A living nerve, laid bare, can be stimulated artificially in a number of ways; there are but two kinds of stimuli, however, the effect of which is instantaneous and whose strength can be accurately regulated, namely mechanical and electrical stimuli. Mechanical stimulation has been considerably improved by an artifice of Schafer[1]), who used falling drops of mercury instead of electrically driven little hammers. When using droplets the size of which is about equal to the breadth of the nerve, even with a very small height of fall distinct effects we obtain, manifesting themselves by contraction of the muscle which has remained connected with the nerve. Schäfer himself obtained this result with a drop weighing 100 mgr. falling through 10 mm. In our laboratory his method gave still better results; an effect was noticed already with a drop of 50 mgr. and a height of fall of 5 mm. Such a drop possesses at the end of its fall an energy of 24.5 ergs. Not the energy as such is a measure of the stimulus, however. Apparently the energy has also in this respect to be considered as consisting of an intensity-factor and a capacity-factor[2]), and this

[1]) Proc. Physiol. Soc. 26 Jan. 1901.

[2]) W. Ostwald. Ber. d. k. Sachs. Ges. d. Wissenschaften 1892, math. physik. Cl. S. 215.

G. Helm. Die Energetik in ihrer geschichtl. Entwicklung 1898 S. 277.

10*