Physics. — *"Note on the interpretation of spectroheliograph results and of line-shifts, and on anomalous scattering of light."* By Prof. W. H. JULIUS.

(Communicated in the meeting of April 29, 1910).

The puzzling character of solar problems is well illustrated by the fact, that the images obtained with the spectroheliograph give rise to widely different explanations, and that it seems impossible as yet to answer in a satisfactory way even the fundamental question: what is the principal cause of the very unequal distribution of different kinds of light over the sun's disk?

HALE and ELLERMAN, in a paper "On the nature of the hydrogen flocculi and their structure at different levels in the solar atmosphere" [1]) reject the hypothesis advanced by W. J. S. LOCKYER, that the dark hydrogen flocculi indicate regions where there is a deficiency of hydrogen. They also refute DESLANDRES' argument, according to which those dark flocculi are not mainly due to a particular distribution of the emissive or absorbing power of hydrogen, but to a simple instrumental cause, an inherent defect of the spectroheliograph. In their own opinion, the best way to account for the observed phenomena is the hypothesis, that the dark hydrogen flocculi are produced by increased absorption (probably resulting from greater depth and decreased temperature of the hydrogen gas in these regions of the solar atmosphere), while the bright flocculi represent regions of increased radiation. Finally HALE and ELLERMAN state, that the results obtained in the high dispersion work with the hydrogen lines are also in accord with certain inferences which I deduced [2]) from the hypothesis first advanced in 1904 [3]), that the distribution of the light in photographs, taken with the spectroheliograph, is mainly caused by anomalous dispersion. They wish to defer a general discussion of the effects of anomalous refraction in the solar atmosphere until many more observations have been made; but a preliminary survey of the results already obtained induces them to believe that the principal phenomena of the dark hydrogen flocculi may be explained more satisfactorily as absorption effects, and that the evidence can hardly be considered favourable to my theory.

In the present note I wish not to combat the absorption hypo-

1) HALE and ELLERMAN, Proc. Roy. Soc. **83**, 177, January 1910.

2) JULIUS, Anomalous refraction phenomena investigated with the spectroheliograph Proc Roy. Acad. Amst. XI, p. 213 (1908).

3) JULIUS, Spectroheliograph results explained by anomalous dispersion. Proc. Roy. Acad. Amst. VII, p. 140, (1904). Astroph. Journ. **21**, 278, (1905).

thesis proposed by HALE and ELLERMAN, but only to show, that their objections to an explanation on the basis of anomalous dispersion are easily refuted, and that the results so far obtained are by no means less favourable to the theory which ascribes the flocculi in the main to anomalous dispersion, than to that which explains them as mere absorption effects.

The intensity and width of the hydrogen lines, especially of H_α, differ greatly in different regions of the sun. If the widening of these lines is caused by increased absorption only, there is no reason to expect them to be asymmetrical (except perhaps by local displacements in consequence of motion in the line of sight). If, on the other hand, we are chiefly dealing with dispersion bands[1], enveloping the real absorption lines, so that the widening results from the fact that the strongly refracted waves bordering the central lines, have their origin on the average in less luminous regions — then, at first sight, it seems as if a marked and variable asymmetry must be the general appearance. Indeed, when comparing waves at equal distances from the centre of the line on the red and violet sides, we must find the rays curved in opposite directions by the same density gradients of the solar atmosphere HALE and ELLERMAN think it improbable that equal amounts of light would reach the observer in both cases, and therefore conclude that, if anomalous dispersion were the principal cause, the spectroheliograph should, as a rule, give very different images when set on the one or the other side of the same line.

They tried the effect of photographing the flocculi simultaneously with light from opposite sides of the H_α line at equal distances from the centre. In general the two images proved to be almost identical in their principal features, though small differences of detail were often visible. In the case of what they call "eruptive phenomena" the images were very unlike, as the distortion of the H_α line would lead one to expect. It stands to reason that, if such distortions are satisfactorily explained on the basis of the DOPPLER effect, a corresponding explanation can be given of the unlike parts in the images just mentioned.

These are the considerations, adduced by HALE and ELLERMAN in support of their conclusion, that the results hitherto obtained are unfavourable to the anomalous dispersion theory.

On closer examination, however, the consequences of anomalous dispersion turn out to be in harmony with the observed phenomena.

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[1]) JULIUS, Proc. Roy. Acad. Amst. VII, p 134–140; IX, p. 343–359; Astroph. Journ. 21, p. 271–291 (1905), 25, p. 95–115 (1907).

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It will indeed prove very probable that R-light and V-light [1]) selected at equal distances from H_α should, in spite of their opposite curvature, produce images which are in general almost identical in their principal features, and that differences of detail should chiefly appear in much disturbed regions, where steep density gradients occur.

In a paper on "Regular consequences of irregular refraction in the sun" [2]) I attempted to obtain a general idea of the optical effect which local condensations and rarefactions in the solar atmosphere must produce, if only the incurvation of rays is taken into account.[3]) The result was as follows.

Let us first consider light for which the refracting power ($n-1=R\Delta$) of the solar atmosphere has a certain *positive* value. Somewhere on the central part of the disk we imagine in the gaseous envelope a region of any shape, only satisfying the condition that, from the outline inward, the density of the gases either diminishes or increases continuously, so that the region includes either a minimum or a maximum of density. In both cases the region will show a dark rim. If in these two cases the density gradients, though opposite in sign, were equal in magnitude, the optical images, presented by the rarefaction or the condensation, would be almost identical in their principal features. This is due to the fact, that the light, transmitted by our region, comes from a source, extending nearly symmetrically round the line of sight. As soon as the latter condition is not fulfilled, if e. g. some of the rays, before entering our region, had already suffered strong deviation in a neighbouring very marked density gradient, the symmetry of the apparent source of light would be disturbed, and then the aspect of the rarefaction might sensibly differ from that of the condensation of the same shape.

Let us now consider light for which the refracting power of the solar atmosphere is equal in absolute magnitude, but *negative*. Such

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1) By R-light and V-light will be denoted waves on the red and violet sides of absorption lines within the limits where anomalous dispersion is perceptible.

2) Julius, Proc. Roy. Acad. Amsterdam XII, 266, 1909; Memorie della Società degli Spettroscopisti italiani 38, 173, 1909; Physikalische Zeitschrift 11, 56, 1910.

3) It may be well here to remark, that in the paper referred to as well as in former publications on anomalous dispersion I never thought of denying the probable effects of selective radiation, absorption, scattering, radial motion. pressure, radio activity, magnetism; but because in solar literature full attention is generally paid to most of these subjects, whereas refraction and anomalous dispersion are little noticed, I wished to consider the latter agencies separately, and to inquire which solar phenomena may be produced or influenced by them. The object in view was not a theory of the sun, but a study of the cosmical consequences of anomalous dispersion.

waves behave in a rarefaction just like the other waves, first considered, would do in the condensation that would be obtained by reversing the gradients. The optical effect is generally the same in its principal features.

Consequently, confining our attention to the central parts of the disk, and excluding the much disturbed regions, we must expect to find only small difference between spectroheliograph images taken with R-light and V-light selected at the proper distances from an absorption line.

HALE and ELLERMAN admit that the small differences frequently observed when we compare images given by opposite sides of H_α are, perhaps, due to anomalous refraction; I see no reason why the same principle should be inactive in the production of the remaining, almost identical, parts of the images.

As we approach the limb, the conditions of refraction are however modified.

When seen projected on the disk at a sufficient distance from the centre, a region with a minimum and a region with a maximum of density will appear different. With R-light the rarefaction shows *dark* on the side *opposite* the centre of the disk, and may be *brighter* than the surroundings on the side *facing* the centre, whereas the condensation shows *dark* on the side *facing* the centre, and may come out *bright* on the *opposite* side. With V-light these effects are the reverse, rarefaction and condensation optically changing parts [1]). So we have reason to expect that between spectroheliograms, taken with light from the red and violet sides of a line, some systematic differences of detail — increasing as we proceed from the centre toward the limb, and relating to distribution of brightness rather than to structure — will be observed.

It will prove necessary, however, to check the latter expectation, because there is a physical law, not hitherto considered in our argument, which tends to efface the differences just mentioned, and to promote similarity of the corresponding R-light and V-light images all over the disk. I mean the fact, discovered by RAYLEIGH, that the light is *scattered* by the molecules of a transmitting medium.

Effects of scattering on the character of the total radiation transmitted by stellar atmospheres were first considered by SCHUSTER in a most interesting article: "Radiation through a foggy atmosphere"[2]). It would lie beyond the scope of the present note to discuss the general bearing of the remarkable results, there described, upon

1) Proc. Roy. Acad. Amsterdam XII, p. 269 and 274—276 (1909).

2) SCHUSTER, Astroph. Journ. **21**, 1—22, 1905.

conclusions deduced from the anomalous dispersion theory. One point, however, which may prove very important with respect to the explanation of spectroheliograph results, requires our special notice, viz., that scattering is a *selective* process. This peculiarity was alluded to on p. 17 of SCHUSTER's paper, but not further considered there.

Indeed, if we accept RAYLEIGH's formula, the coefficient of scattering, called s in SCHUSTER's paper, depends not only on the number N of scattering particles per unit volume, and on the wave-length λ of the light under consideration, but also on the index of refraction n of the medium:

$$s = \frac{32\pi^3 (n-1)^2}{3N\lambda^4}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The terms "anomalous dispersion" and "anomalous refraction" were until now used indiscriminately. We shall in future distinguish between the two expressions. By anomalous dispersion we denote the general property of matter, that its refracting power $\pm (n-1)$ varies rapidly as we approach an absorption line. This property, of course, subsists even when the density of the medium is perfectly uniform, and the propagation of light in it rectilinear. Whenever the density is not uniform, it may cause very different deviations of neighbouring waves. That effect of anomalous dispersion — which I exclusively studied in former papers on the subject[1]) — will be called *anomalous refraction*. Another effect, dependent on the same property, and now considered for the first time, is *anomalous scattering*.

Equation (1) shows, that the coefficient of scattering passes through a sharp maximum in the neighbourhood of every value of λ which corresponds to an absorption line, because there the factor $(n-1)^2$ increases rapidly as we approach the line from either side. In the nearest vicinity of the absorption lines of a mixture of gases RAYLEIGH's formula is perhaps not rigorously applicable, but we may use it as a first approximation.

Even absolutely monochromatic absorption would thus, in an extensive atmosphere, give rise to a line of a certain width. If a group of neighbouring waves are absorbed, the width of the resulting

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[1]) I am very much indebted to Prof. LORENTZ, who, at my request, was kind enough to subject my preceding work on the consequences of anomalous dispersion to a thorough criticism. According to him the weak side of my conclusions was, that I had not duly noticed the diminution of the light by scattering. I intend to discuss this important point more fully on a later occasion. The resulting new aspect of the anomalous dispersion problem will render necessary certain modifications of the theory (e g. regarding the explanation of prominences), and may thus perhaps serve to reconcile opposite opinions on this matter.

dark line will always exceed that of the spectral region of real absorption. Every absorption line of a stellar atmosphere is, therefore, enveloped in what we may call a *dispersion band*, because it depends upon anomalous dispersion. In an atmosphere of perfectly uniform density, the dispersion band would be caused by anomalous *scattering* only; but if irregular density gradients occur, anomalous *refraction* adds to the effect in two ways: 1 by directing back toward the luminous surface some of the strongly refracted rays [1]), and, 2, by lengthening the paths along which the beams are subject to loss of intensity by scattering.

These notions may gain clearness if we imagine ourselves to be placed somewhere in the solar atmosphere, looking outward. Then a spectroscope, if directed on the "solar sky", would show us the Fraunhofer lines bright on a less luminous ground, not only on account of luminescence or of selective temperature radiation, but also because the scattering is more intense in the vicinity of absorption lines than in blank parts of the spectrum. The energy which thus returns to the sun by the *scattering* process, is wanting in the Fraunhofer spectrum as seen on earth. Besides, the irregular density gradients of the solar atmosphere would give rise to "mirage" on a large scale, also of a selective character. Distorted images of parts of the brilliant solar surface would appear everywhere in the sky, different in shape and extension for kinds of light that are differently refracted. This is the portion which anomalous *refraction* contributes to the returning energy, and withdraws from the radiation leaving the sun.

Applying our ideas on the combined consequences of anomalous scattering and refraction to the interpretation of spectroheliograph results, we must remember:

1. that anomalous scattering darkens the solar spectrum almost equally on both sides of a strong absorption line [2]), thus reducing the differences which photographs made with R-light and V-light at equal distances from the same line would have shown, if anomalous refraction were the only agent;

2. that the width of a certain Fraunhofer line would be a minimum at points of the sun's image corresponding to regions of uniform

[1]) This process was more fully treated of in my paper on "Regular consequences of irregular refraction in the sun", Proc. Roy. Acad. Amst. XII, p. 279.

[2]) It will be mentioned farther on, that especially the weaker Fraunhofer lines are asymmetrical by anomalous dispersion. So long as spectroheliograms are only made with light from the domain of strong lines, we may, in interpreting them, neglect that systematic asymmetry.

density and composition in the solar atmosphere, because there anomalous scattering would be the only cause of the dispersion band;

3. that the same line will be wider and, in general, darker in the spectrum of regions where irregular gradients disturb the rectilinear propagation of the light. (In this way we explain the varying width of H_γ, as shown in Fig. 2 of Pl. I, Proc. Roy. Soc. Vol. 83 p. 189. If, therefore, the camera slit of the spectroheliograph is set e.g. between the centre and the edge of H_α, but nearer to the edge, the dark flocculi indicate regions, where density gradients with large components perpendicular to the line of sight are in evidence. Almost the same structure must be revealed, if the camera slit is set on H_β or H_γ, provided the distance from the centre of these lines be taken smaller than with H_α, in order to catch waves that are refracted to the same degree as those in the former case. This connection between spectroheliograms obtained with different hydrogen lines was predicted in my paper Proc. Roy. Acad. Amst. XI, on p. 221, and afterward found confirmed by HALE and ELLERMAN); [1])

4. that gradients of exceptional magnitude and extension may (by refraction) produce marked irregularities in the distribution of the light within the range of a dispersion band;

5. that the composition of the solar atmosphere very probably varies with the level, but that convection currents tend to efface local differences of composition as well as of temperature.

If these statements are kept in mind, it will be found possible to explain, on the basis of anomalous dispersion, at least as many particulars of the spectroheliograms, as were explained by HALE and ELLERMAN on the basis of their temperature and absorption hypothesis. We will not, on this occasion, enter into a comparison of the advantages of both points of view, the principal aim of the present paper only being to prevent a premature criticism of either of them.

With a similar object in view we shall now consider another important solar phenomenon — systematic displacements of Fraunhofer lines — which was also explained according to two entirely different theories.

I showed elsewhere [2]) that anomalous refraction by irregular density gradients causes the Fraunhofer lines to be asymmetrical, the narrower ones generally to a higher degree than the wider ones, thus producing an apparent displacement of the lines toward the red. The displa-

1) The optical effect produced by the systematized density gradients near vortices requires special treatment.

2) See the paper on "Regular consequences etc." referred to above.

cement must increase when we pass from the centre of the disk to the limb. These effects depend upon the rule, that the refracting power of the mixture of gases, constituting the solar atmosphere, is on the average greater on the red side of an absorption line than on the violet side. Anomalous scattering also being determined by the values of the refracting power on both sides of the absorption lines, it co-operates in producing those systematic displacements.

From a recent remarkable investigation of the displacements of the spectrum lines at the sun's limb, by W. S. ADAMS [1]), it appears that out of a total of 470 lines only one or two are shifted unmistakably toward the violet; the other lines all show displacements to the red, ranging from 0,000 to 0,014 Angström. The various characteristics of the list of these lines will have to be studied in detail from the point of view of anomalous dispersion. I must defer that inquiry to a later date, and now confine myself to a few remarks on prominent statements made in ADAMS' paper.

ADAMS concludes that pressure is the effective agent in producing the displacements observed. He evidently paid very little attention to the possibility of explaining these phenomena by anomalous dispersion, for although he refers to the explanation which I recently published in the Memorie della Società degli Spettroscopisti Italiani, and rejects it, the clue of my argument entirely escaped his notice. Indeed, he writes:

"According to his (JULIUS') point of view the photospheric light is anomalously refracted in the vicinity of the absorption lines produced by the metallic vapours, and, since in general the density-gradient decreases outward, the widening will be upon the red side of the lines producing the observed displacements. The fact that the sodium lines D_1 and D_2 are not displaced, although they show the largest amount of anomalous dispersion of any which have been investigated for this effect, is rather strongly opposed to this view".

In the first place I do not quite understand, why the decrease of the density-*gradient* should be material to the case. This, however, may be a lapse; probably the author intended to say: "since in general the density decreases outward." But then the inference expressed in the sentence as a whole is erroneous. A little reflection will easily show, that in parts of the disk near the limb the regular radial density gradient assists R-light and hinders V-light in curving from the photosphere toward the observer. The result would be an apparent displacement of the dark line to the *violet*, not to the red. The radial

[1]) ADAMS, Contrib. from the Mount Wilson Solar Obs. No. 43; Astroph. Journ. **31**, p. 30—61, 1910.

gradient, therefore, if it is of any importance in this matter, counteracts the effective agent which produces the observed shifts toward the red.

The principal point overlooked by ADAMS is that, according to my explanation, the effective agent in producing the phenomenon is the general asymmetry of the dispersion bands enveloping the absorption lines of the solar spectrum. It does not depend upon the incurvation which rays undergo in the regular radial density gradient of the solar atmosphere, but is caused by anomalous scattering, and refraction in irregular gradients, combined with the fact that the refracting power of the mixture of gases is on the average greater for R-light than for V-light.

If we keep this in mind, we shall have a useful base for investigating the relationship between anomalous dispersion and the results of ADAMS' measurements. That a simple comparison of GEISLER's observations on anomalous dispersion of metallic vapours in the arc with displacements at the limb — as given by ADAMS [1]) — could not possibly serve the purpose of finding such a relationship, is evident; for the amount of that part of the displacement which is due to anomalous dispersion, is determined by the degree of asymmetry of the Fraunhofer line under consideration; and this asymmetry is not a mere property of the corresponding element itself, revealable in laboratory experiments, but depends upon the concentration with which that element is represented in the solar atmosphere. No shade of proportionality between the results of those two investigations could be expected. So it is not at all opposed to our view, that the winged lines of sodium and calcium are little or not displaced at the limb, although they show strong anomalous dispersion. On the contrary, that result might have been foreseen; for if the wide wings are really owing to that cause, the wave-length corresponding to the zero value of the refracting power of the mixture, which always lies on the violet side of a Fraunhofer line, must be at a rather great distance from the absorbed waves [2]), thus making the asymmetry of the dispersion band imperceptible. The central part of the line, the true absorption line, cannot be displaced by anomalous dispersion.

A peculiar feature of our explanation is, that both very strong and very weak anomalous dispersion make the displacements small, whereas intermediate values give larger displacements. Indeed, with decreasing width of the dispersion band, its asymmetry increases;

[1]) ADAMS, l. c. p. 28.

[2]) Cf. fig. 8 on Plate I, Proc. Roy. Acad. Amst. XII p. 282. 1909.

but the resulting apparent displacement can never surpass half the width of the line. (Whenever greater shifts are observed, pressure or magnetism or Doppler-effect certainly come into play).

The largest displacements observed by ADAMS occur with many lines of iron and nickel. From the point of view of our hypothesis this means, that near these lines the amount of anomalous dispersion of the mixture is most suitable for producing the phenomenon, neither too great, nor too small. Considerably smaller are the displacements for titanium, vanadium, and scandium — perhaps because those elements are less in evidence in the mixture of gases. That those iron lines, which are most strengthened at the limb, show smaller displacements than the average iron lines, also perfectly fits our point of view, for their asymmetry must be less conspicuous on account of their greater width. That the lines of the elements of very high atomic weight, such as lanthanum and cerium, show very small displacements, is easily accounted for if we assume their vapours to be extremely rare in the solar atmosphere. This explanation is certainly not less simple than the one proposed by ADAMS on p. 17 and 18 of his paper, [1]) where he has to find a way out of the discrepancy to which in this case the pressure hypothesis seems to lead.

Various other characteristics of ADAMS' interesting list of displacements (e. g. the special behaviour of the enhanced lines as a class) will be discussed on a later occasion, together with his equally valuable observations of the spectrum of sun-spots.

Geophysics. "*On the determination of the epicentre of earth-quakes by means of records at a single station*". By Dr. C. BRAAK. (Communicated by Dr. J. P. VAN DER STOK).

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In working out seismograms of the WIECHERT-seismograph I was repeatedly struck by the fact that the azimuth of the epicentre could be determined with satisfactory results from the two components of the motion of the ground.

As informations relative to other stations are generally received at Batavia some time after the occurrence of earth-quakes, I have often used this method to come to a preliminary determination of the epicentre from the Batavia seismograms only. In this way e.g. informations concerning the *Korintji* earth-quake of June 4, 1909 could be

[1]) Astroph. Journ. 31, 46—47, 1910.