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Physics. — *"Anomalous refraction phenomena investigated with the Spectroheliograph."* By Prof. W. H. Julius.

According to the current interpretation of spectroheliograph results, *dark* flocculi indicate regions on the sun, where the special gas, a line of which is used, exists in such conditions of density and temperature, that it strongly absorbs the light coming from deeper layers, whereas *bright* flocculi show us regions where, in consequence of higher temperature or chemical or electrical causes, the radiation of the gas exceeds its absorbing effect.

A few years ago I proposed an entirely different explanation of the same phenomena[1]. An attempt was made to account for the peculiar distribution of the light in photographs, secured with the spectroheliograph, by simply considering the anomalous refraction which waves from the vicinity of the absorption lines must suffer when passing through an absorbing medium, the density of which is not perfectly uniform.

If it proves possible to explain the observed facts on this basis, we shall be able to dispense with the assumption of any very marked differences as to the absorbing and emitting conditions of a certain gas or vapour in contiguous regions on the sun. Moreover, we then *might* assume the constituents of the solar atmosphere to be thoroughly mixed, their proportions in the mixture only varying with the distance from the sun's centre.

That our interpretation does not presuppose the separate existence of cloud-like masses of calcium or iron vapour or of hydrogen, simplifies the conception of the solar body, and therefore looks like an advantage; but even if one were compelled, by other considerations, still to believe in the real existence of such separate luminous or dark accumulations of certain substances, it would nevertheless be necessary to consider the effect, which anomalous dispersion of light in those masses must have on the appearances revealed by the spectroheliograph.

Among the advantages I derived from a visit to the Mount Wilson Solar Observatory, in August 1907, was the opportunity of using the 5 foot spectroheliograph[2]) for some experiments on anomalous refraction.

It was expected that when light, coming from a source with a continuous spectrum, traverses a space in which sodium vapour is

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[1]) Proc. Roy. Acad. Amsterdam VII, p. 140, (1904).

[2]) Hale and Ellerman. "The five-foot spectroheliograph of the Solar Observatory." Contributions from the Solar Observatory Mount Wilson, California, N⁰. 7.

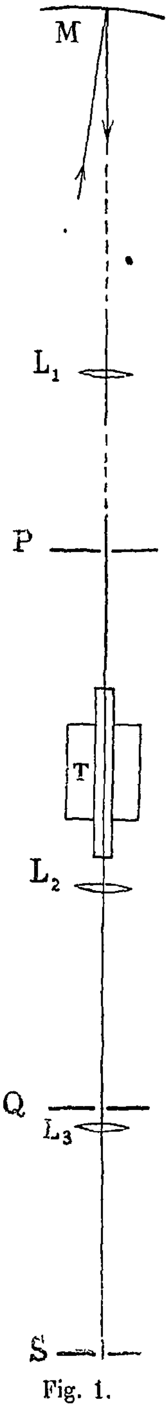

Fig. 1.

unequally distributed, particulars concerning the distribution would be revealed by the spectroheliograph through the *refracting* power of the vapour, rather than through its absorbing and emitting power. This expectation could be put to the test.

As an equipment for the study of anomalous dispersion phenomena in sodium vapour, exactly similar to the one described in my paper on "Arbitrary distribution of light in dispersion bands"[1]), had already been procured for the solar observatory by Professor HALE, the experiments were readily made, thanks to the laboratory facilities available on the mountain.

The apparatus consists of a wide nickel tube, 60 c.m. long, the middle part of which is placed in an electric furnace, while the projecting ends are cooled by jackets with flowing water. The tube contains a few grammes of sodium and is permanently connected to a Geryk-pump to remove the air and the gases which escape from the sodium during the first stages of the heating process. An arrangement is provided for, by which density gradients of various known directions and arbitrary magnitude may be produced in the sodium vapour.

Sunlight coming from the 60 feet mirror M (fig. 1) of the Snow telescope[2]) passes through the tube T on its way to the slit S of the spectroheliograph. The distance between T and S is about 560 c.m. A lens L_1 gives an image of the sun near the middle of the tube T. P is a diaphragm with an adjustable slit, of which the lens L_2 projects an image in the plane of the diaphragm Q. Just behind the latter is a lens L_3; in combination with L_2 this forms an image of a section of the tube in the plane of the slit S of the spectroheliograph. In this image (fig. 2) the rectangular windows of the caps of the tube will of course come out with somewhat blurred edges, as only a section lying somewhere *between* the caps would show sharp. In A and B are projected the narrow nickel tubes[3]),

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[1]) Proc. Roy Acad. Amsterdam, IX, p. 343. (1906).

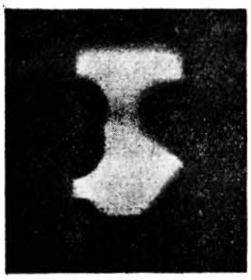
[2]) Described in: Contributions from the Solar Observatory Mt. Wilson, Cal., Nos. 2 and 4.

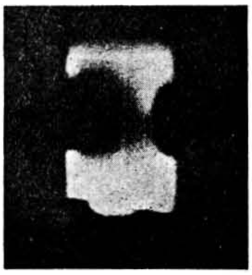
[3]) See description in: Proc. Roy. Acad. Amsterdam, IX, p. 345.

W. H. JULIUS. “Anomalous refraction phenomena investigated with the spectroheliograph.”


α


β


γ


δ


ε


ζ


η


θ

of which, for producing the required density gradients, the temperature may be varied at pleasure by forcing an electric current or an air current through them.

Cooling one of the tubes by an air current causes sodium vapour to condense on it; so, in course of time, drops of molten metal will hang from the tubes and fall off again.

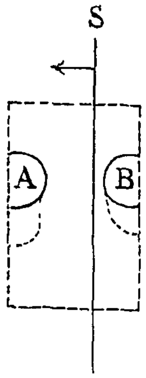


Fig. 2.

When a photograph is made, the first slit S of the spectroheliograph moves across the image in the direction of the arrow (fig. 2), and at the same time the second slit moves across the photographic plate.

Let us suppose the openings in P and Q (fig. 1) to be so adjusted, that the image of the slit in P exactly coincides with the slit in Q. Then all the light which passes through P and traverses the vapour along straight lines, is transmitted by Q and therefore contributes to the intensity of the image of the tube-section. Waves however that deviate so much in the sodium vapour as to be intercepted by the screen Q, will be absent from the spectrum of the transmitted light.

If the furnace is slowly heated to 380° or 390°, the density of the vapour is pretty uniform in the middle part of the wide tube and falls off towards the ends; but as the direction of these density gradients nearly coincides with that of the beam of sun-light, even the waves subject to anomalous dispersion will hardly deviate from the straight path. The D-lines in the spectroheliograph retain about their normal appearance. If now we blow air through the tube B, density gradients are produced all around it in directions perpendicular to the axis of that tube. The D-lines no longer show the same appearance throughout the field. In the spectrum of those parts of the field where perceptible gradients occur, the D-lines now appear winged; they are indeed enveloped in *dispersion bands.* As the width of these bands depends on the magnitude of the gradient, it will, in our case, vary along the lines and reach a maximum at the place in the spectrum which corresponds to the plane passing through the axes of the tubes A and B. And with increasing distance between S and B (fig. 2) the width of the bands will diminish.

Let us consider the monochromatic images of the tube-section produced by the spectroheliograph if the camera slit is set at different distances from the D-lines.

With the camera slit at λ 5850, outside the region of the dispersion band of D_1 the illumination of the field is uniform (see the Plate, *a*);

nothing is visible of the density gradients existing round the cooled tube B, because light of this wave-length travels along straight lines through the vapour.

Proceeding to λ 5870, we are still at such a distance from D_2, that the value of $\frac{1-n}{\Delta} = R$ (n representing the index of refraction, Δ the density of the vapour) is moderate. Steep gradients of the density are required to make the rays deviate sufficiently for missing the slit in Q, and such gradients are only to be found very near the surface of the tube B. We therefore obtain the image β, in which B appears surrounded by a narrow dark region.

The third photograph, γ, has been made with λ 5877. For these waves the expression $\frac{1-n}{\Delta}$ is greater than for λ 5870, so that smaller values of the gradient suffice to give to the rays a perceptible incurvation. The result is a broader dark region all round B[1]).

The photographs δ and ε have been secured with the camera slit on λ 5881 and λ 5885 respectively. This time the tube A has been cooled instead of B. We see the dark "aureole" grow as the wave-length we are using approaches $\lambda_{D_2} = 5890$. Getting nearer still, the whole field would finally become dark.

Similar results are obtained if we approach D_1 from the side of the *greater* wave-lengths, thus using waves for which $\frac{n-1}{\Delta}$ has increasing values.

By a slight change in the arrangement of our experiment we may obtain the opposite effect, to wit, that merely rays, suffering anomalous refraction, do enter the spectroheliograph, whereas the normally refracted light is prevented from reaching the slit. We have only to open the slit in P very wide, and to put a vertical bar (a match for instance) in the middle of it, the image of which now falls exactly on the slit in Q. Under these circumstances light, issuing from the divided opening in P, can only be transmitted by Q if it has been deflected in the vapour.

In this way the photographs ζ, η and θ were obtained, the second slit being set on λ 5884, λ 5886, λ 5888 respectively. If there had been no density gradients, the whole field would have shown dark; the *bright* regions, however, now prove the existence of the gradients. When taking ζ and η, the tube B, and when taking θ, the tube A was cooled.

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[1]) In this image the lower right corner was cut off by a rubber tube accidentally crossing the path of the beam.

The following general statement is borne out by these experiments. If an illuminated absorbing vapour is investigated by means of the spectroheliograph, and the camera-slit of the instrument is set *on the edge* of a dispersion band, marked irregularities in the brightness of the field will only appear at those places in the image which correspond to regions with *large* density gradients in the vapour. Setting the slit *nearer to the middle* of the dispersion band, we shall get evidence, in the image, also of regions with *smaller* gradients, a.s.o. Particulars regarding the distribution of a vapour are thus clearly shown by the spectroheliograph through anomalous refraction, even in cases, where the absorbing or emitting power of that medium would have failed to reveal its structure.

The bearing of these inferences on astrophysical phenomena has now to be considered a little more closely.

Suppose we have a large mass of absorbing vapour of such average density, that, if it were uniform, its absorption lines would appear rather narrow; and of such temperature and condition of luminescence that its emission lines are very faint. As soon as the density of this mass becomes irregular, some parts of it may give rise, when traversed by light from another source, to the appearance of dark or bright dispersion bands, greatly exceeding in width and strength its absorption or emission lines.

It is therefore *possible,* that anomalous refraction plays a very essential part in the production of those phenomena which the student of astrophysics observes with his spectroscope or spectroheliograph; we must inquire how far this is also *probable.*

One might be inclined to object, for instance, that in our experiment the use of a narrow and sharply limited source of light, placed at a fair distance behind the vapour, seemed to be a necessary condition for obtaining any marked dispersion effects, and that in the sun similar circumstances are very unlikely to prevail. Indeed, the bulk of the sun — whatever the nature of the photosphere may be — is a large incandescent mass, closely surrounded by the absorbing vapours, so that the "source of light", if considered from a point of the chromosphere, subtends a solid angle of nearly 2π. The reversing layer and the chromosphere have sometimes been compared to a thin, transparent layer of selectively absorbing varnish, covering a luminous (e.g. phosphorescent) globe: the photosphere. It seems very improbable that refraction in density gradients of such a transparent envelope should be able to disturb to any perceptible degree the uniform brightness of that globe.

The comparison, however, is entirely misleading, because, so far, an essential relation between absolute size and density gradients is overlooked in it. But if carried through properly, it will lead us to the opposite conclusion, namely that refraction in the solar atmosphere must alter the distribution of the light on the disk entirely.

If we wish to form an image, on a reduced scale, of the sun considered as a refracting body, we have to reduce the radii of curvature of the rays in the same proportion as we do the diameter, for instance 10^{10} times (so as to make the diameter of the photosphere 14 cm.). By the general equation[1])

$$\frac{d\Delta}{ds}=\frac{1}{R\varrho} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

we know that, for a given value of the refraction constant R, the radius of curvature ϱ of a beam of light is in reverse proportion to the density gradient $\frac{d\Delta}{ds}$ in the direction toward the centre of curvature. In our image, therefore, the density gradients have to be taken 10^{10} times as great as they are in the sun.

Let us suppose that at a certain level in the solar atmosphere irregular density gradients occur, which are of the same order of magnitude as the radial (vertical) density gradient in our earth's atmosphere, viz. 16×10^{10} [2]). At the corresponding points in our image we then have to put $\frac{d\Delta}{ds}=16$. If the layer of "varnish" were really traversed by many density gradients of this order of magnitude, it would be very different from ordinary transparent varnish, and certainly be able to disturb the uniform brightness of the background, like a layer of glass beads or swollen sago grains. Even normally refracted waves would perceptibly deviate in an envelope of this kind. For if in our equation (1) we put $\frac{n-1}{\Delta}=R=0{,}5$ and $\frac{d\Delta}{ds}=16$, we get $\varrho=0.125$ cm., so that the average curvature of such rays is already sufficient for producing sensible changes in the divergence of beams on their way through a shell not thicker than 0.1 cm.

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[1]) Proc. Roy. Acad. Amsterdam, IX, p. 352. (1906).

[2]) The frequent occurrence of density gradients nearly perpendicular to the radii of the sun is rendered more probable still, since increasing evidence has been obtained by Prof. Hale of the existence of solar vortices, in which the convection currents (especially in sun-spots) are sufficiently strong to produce magnetic splitting of absorption lines. (Cf. Nature, Vol. 78, p. 368—370, Aug. 1908).

Waves, suffering anomalous refraction, will of course be much more scattered by the same medium. Let us consider an absorbing substance which, at a certain level, occupies say only 1 percent of the solar atmosphere, taken as a perfect mixture. Its density gradients will then be only $\frac{1}{100}$ of those of the mixture. The refraction constant, on the other hand, for waves near one of its absorption lines, may attain values as high as 1000 or 2000. With $R = 1600$ (as actually observed in sodium vapour, Proc. Roy. Acad. Amst. IX, p. 353), our equation (1) becomes

$$\frac{1}{100}\frac{d\Delta}{ds} = \frac{1}{1600\,\varrho}.$$

In a level where, in our image, the irregular density-gradients of the envelope were supposed to have an average value $\frac{d\Delta}{ds} = 16$, the equation gives

$$\varrho = 0{,}004 \text{ cm}.$$

It is evident that under such circumstances rays may easily deviate 90 degrees and more in the thin shell of transparent matter covering our globe, and thus give rise to a very unequal distribution of the light in photographs of it, secured with the spectroheliograph.

This conclusion holds just as well with regard to the real sun. It follows directly from our *only* assumption, that in some level of the sun irregular density gradients exist, comparable in magnitude with the vertical gradient in the earth's atmosphere. At lower levels, greater gradients, at higher levels, smaller gradients may be expected to prevail. As the validity of this assumption can hardly be doubted, we may infer that the existence of some important influence of anomalous dispersion on astrophysical phenomena is not merely possible, but *exceedingly probable,* in spite of the absence of narrow slits as sources of light.

Although we are free to admit that the phenomena, observed with the spectroheliograph on the solar disk, are perhaps in part due to selective radiation, dependent on various conditions of temperature or luminescence, we may nevertheless inquire into some consequences to which one is led if only the effects of refraction in a mixture of vapours are considered.

The composition of the solar atmosphere cannot be the same at all levels. As we get lower down, the percentage of heavier molecules is likely to increase; but we should not presume too much as to the order in which the elements will come into evidence, on account of possible condensation, and because the pressure of radiation counteracts gravitation to a degree that depends on the size of the particles, and, therefore, on numerous unknown conditions prevailing in the sun.

Yet for each element a certain level must exist, in which its percentage in the mixture is a maximum. Accordingly, the refracting properties of successive layers will be governed by different elements. A photograph, made with the spectroheliograph in a hydrogen line, shows a structure which, of course, depends on the distribution of all the hydrogen present in successive layers, but is chiefly determined by the density gradients in a rather high level; whereas a photograph, made with an equally strong iron-line, reveals more especially the structure of lower regions. This explains the difference in character between iron- and hydrogen plates.

It must be possible, on the other hand, to obtain almost identical photographs with different lines, provided they belong either to the same element, or to elements that are most in evidence at about the same level in the sun; but then another condition has also to be fulfilled, viz. that the camera-slit transmits rays of the same refrangibility in both cases. If for instance Fig. 3 represents the dispersion curve near H_α and near H_δ, the width and the position of the camera-slit ought to be so chosen, as to let in only waves corresponding to parts of the curve, enclosed between equal ordinates in the two dispersion bands [1].

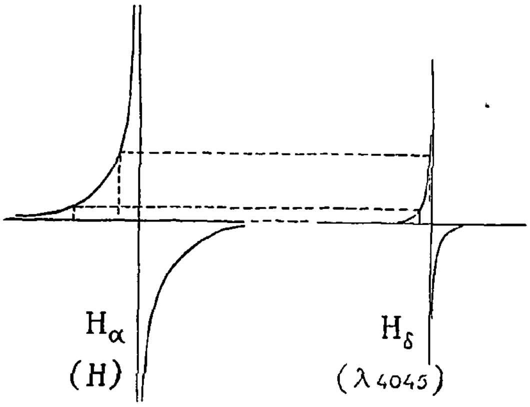

Fig. 3.

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[1] Waves, lying more or less symmetrically on either side of an absorption line, and answering the relation $n-1=1-n'$ between the indices of refraction n and n' of the medium for them, must give nearly the same spectroheliograph results on the greater part of the disk. This follows from a discussion of the various possi-

Recently it has been found by Prof. HALE that, while the H_β-, H_γ- and H_δ-lines give very similar results, photographs with the much stronger line H_α are widely different in some respects 1). Bright flocculi appear on these plates at points where no corresponding objects are shown by H_δ. Moreover, the dark H_α-flocculi, while showing a general agreement in position and form with those of H_δ, are stronger and more extensive. In some instances, however, small areas appear dark in H_δ which are absent or fainter in H_α. Such differences are of the same character as those observed between photographs made with the slit in the broad calcium-bands *H* or K at various distances from the central line. They may find a corresponding explanation if we assume that the rays, used in the H_α photographs, were on the average refracted to a higher degree than those, used in the H_δ-photographs, but both by the same system of density gradients. It is not improbable, therefore, that in the wings of H_α waves may be selected so as to give spectroheliograph results, closely resembling H_δ-plates.

That also lines of *different* elements may give very similar results with the spectroheliograph, is exemplified by the case of calcium and iron. Among the beautiful collection of photographs secured on Mount Wilson I saw several iron-(λ 4045)-plates rather closely resembling certain calcium-(H_1)-plates of the same daily series. As the atomic weights of calcium and iron are not so very different, and their levels of maximum density therefore probably not far apart, the refraction caused by these elements may bring out the density gradients of nearly the same layer of the solar atmosphere. It will do so by showing a similar distribution of the light in the two photographs — provided that rays of the same refrangibility are used in both cases. And this condition may be fulfilled by setting the camera slit on corresponding regions of the spectrum, in the sense as illustrated by Fig. 3, if we imagine it now to bear on the calcium-(*H*)-line and the iron-(λ 4045)-line.

With a calcium- and a hydrogen-line such similarity could not be found.

Far more evidence will of course be required before we shall be able to decide whether or not anomalous dispersion is the principal agent in determining the flocculent appearance of the solar disk.

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bilities regarding the relative position of density gradients and source of light. Consequently a H_δ-plate, obtained with the camera-slit centrally, so as to embrace the whole width of that rather narrow dispersion band, will scarcely differ, at first sight, from a photograph made with only one of the wings.

2) HALE, "Solar vortices", Contrib. from the Mt. Wilson Solar Obs. No. 26.

Plates secured with many lines of various elements will have to be compared. The mighty 30-foot spectroheliograph of the "tower telescope" of Mount Wilson is excellently adapted to work of this kind, not only on account of its great dispersion permitting the use of finer lines, but chiefly because it is provided with two camera slits, so that perfectly simultaneous photographs with different lines may be secured. By this arrangement, really comparable monochromatic pictures of the sun are obtained, since the otherwise confusing influence of the variable refraction in our atmosphere is thus rendered harmless.

I feel greatly obliged to Prof. GEORGE E. HALE for having procured for me the opportunity of making an investigation at the Mount Wilson Solar Observatory, but more still for his keen and stimulating interest in the problems, suggested by the application of the principle of anomalous refraction in astrophysics. I am also very much indebted to the kindness of Mr. F. ELLERMAN, Mr. W. S. ADAMS and Dr. CH. M. OLMSTED for valuable information and assistance in connection with the inquiry here reported upon.

Physics. — *"The* ZEEMAN-*Effect of the strong lines of the violet spark spectrum of iron in the region* λ 2380—λ 4416." By Mrs. H. B. VAN BILDERBEEK-VAN MEURS. (Communicated by Prof. P. ZEEMAN).

The concave ROWLAND grating used in the experiments here communicated has 14438 lines per inch, a width of 8 c.m., and a radius of curvature of 304.96 c.m. The grating is mounted according to RUNGE and PASCHEN's method.

The spark passed between the iron poles of the magnet in the direction of the line of force. It was originated by the discharge of the secondary coil of a RUHMKORFF, a self-induction and condenser being placed in parallel.

Further details will be given in my thesis for the doctorate.

The time of exposure varies from 30 to 120 minutes.

In order to determine the field strength I made simultaneous exposures of the iron and zinc spectra. The amount of separation of the zinc line 4680.33 was compared with the result of the measurements of COTTON and WEISS (Journal de Physique, June 1908), the strength of field being supposed proportional to the amount of separation.