

Citation:

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its activity about 12 hrs after having been collected, which proved, according to DRENMAN that the exciting factor is highly labile and that the dilution of the diabetic blood cannot be responsible for the result. HÉDON, on the contrary, inquiring into the effect of transfusion of blood by vascular connection, from normal into diabetic dogs, ascribes the decrease of sugar secretion in the diabetic animal only to the dilution of the hyperglycemic blood, while he attributes a strong inhibitory influence on the renal secretion to transfusion.

My experience differs from DRENMAN's in that I did not detect anything at all of a marked lability of the active factor in the pancreatic blood; anyhow, after more than 20 hours subsequent to the removal of the blood, activity was still noted. This may be only a quantitative difference, because in theory there are more active materials in the pancreatic blood than in the general circulation. It also seems to me a sheer impossibility, to attribute the results, reported here, to dilution of blood; first and foremost because the quantity injected was too small in most cases; secondly the injection was subcutaneous, so that resorption was slow; thirdly the action was continued too long (on an average 2 days). In concordance with HÉDON's experiments I detected an influence upon the renal secretion, not in such a marked degree, however, that it could bear up my results. Lastly a permanent influence on the N-elimination was demonstrated.

Physics. "*On the interpretation of photospheric phenomena*". By Prof. W. H. JULIUS.

(Communicated in the meeting of May 31, 1913).

§ 1. It is a common belief that a body always presenting the appearance of a circular disk, from whichever side it is looked at, must be bounded by a spherical surface. The general conviction that the bulk of the sun is an incandescent sphere rests on that belief, and was a natural starting-point for solar theories.

After the effective solar temperature had been found so high as to exceed the critical temperatures of perhaps all known substances, the earlier idea that the main body of the sun was in the liquid or the solid state had to be replaced by the hypothesis that it is substantially gaseous. This new idea involved the necessity of explaining the phenomenon of the apparent "solar surface". One had to choose between YOUNG's view, that the photosphere was a

layer of incandescent clouds produced by condensation of certain substances having exceptionally high critical temperatures, and SECCHI's hypothesis (afterwards developed by SCHWARZSCHILD and EMDEN), which dispenses with assuming cloud-formation by supposing the density of the solar gases to increase so rapidly with depth near the level called "solar surface", that within a layer no more than a thousand kilometers thick, their united radiating power increases from a very low value (in the chromosphere) up to that of the black body (in the photosphere).

In 1891, AUGUST SCHMIDT took a new departure by showing that an entirely gaseous body of the dimensions of the sun, in which the density and the radiating power gradually decrease from the center outward — be it even at a slow rate — must appear like a circular luminous disk with a sharp edge, as a mere consequence of ray-curving caused by the radial density gradient. So the circular aspect of the sun is *not* a sufficient ground for admitting the existence of a real "photosphere", that is, of a layer characterized by some abrupt, or even only rapid change of physical properties.

SCHMIDT's well-known solar theory, however, met with the severe objection that it did not duly consider the effect of absorption and scattering of the light¹⁾. Rays having accomplished such long distances on their spiral paths inside the critical sphere would be almost wholly extinguished before emerging; they could not possibly bring along so much energy from the incandescent core, as would be required in order to account for the brilliancy observed in the marginal parts of the disk. In its original form the optical interpretation of the sun's edge cannot be maintained.

It is also impossible to accept the cloud-theory of the photosphere, because the results of the radiation-measurements made at Maastricht during the annular eclipse of 1912²⁾ forbid making an absorbing or scattering solar atmosphere responsible for the fall of the sun's brightness from the center toward the limb. Indeed, the absorbing and scattering power of the gases lying outside the photosphere proved to be relatively insignificant. The photosphere, therefore, cannot be of such a nature that it would appear like a *uniformly* luminous disk if the surrounding gases were absent. On the contrary, it must have in itself the property of appearing much brighter when looked at in the direction of a radius than at an angle with the

¹⁾ R. EMDEN, Gaskugeln, S. 388—394.

E. PRINGSHEIM, Physik der Sonne, S. 266—270.

²⁾ Proc. Roy. Acad. Amsterdam. XV, 1451, 1913; Astrophysical Journal **37**, p. 225, 1913.

radius; and the law of variation of brightness with the angle is different for different wave-lengths.

Whichever the causes may be, that make the sun radiate more intensely in the direction of the radius than in directions slanting to it, they must be looked for in layers lying *below* the level generally called the surface of the photosphere. Those layers consist of transparent gases, for the slightest haze of condensation products, occupying a stratum some thousand kilometers thick, would provide it with a radiating and scattering power almost independent of direction, which power the photosphere does not possess.

Assuming, on the basis of the Maastricht results, that the extinction effected by the sun's outer layers is comparatively small, we derive from direct observations on the distribution of brightness on the sun's disk (VOGEL, ABBOT), how much light of a given wave-length a point M , lying somewhere in the photospheric level, transmits on the average along the various directions. The result may conveniently be described, for every wave-length separately, by means of an "irradiation surface" $q p q_1$ (Fig. 1)¹⁾, the radii vectores of which

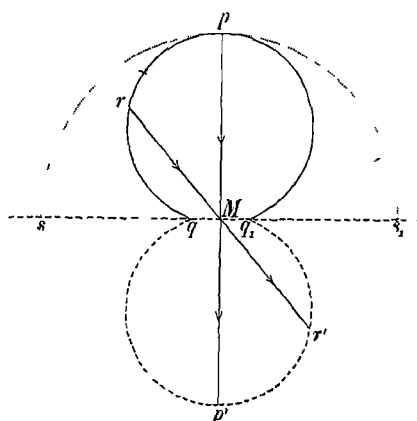


Fig. 1.

represent the average intensities of the light reaching M from different sides. We obtain the "irradiation or emission surface" $p p' q_1$ of M by prolonging the radii rM and making $Mr' = rM$.

If we wish to explain the sun's apparent, fairly sharp, boundary, and the law of varying brightness of the solar disk, we shall have to consider, besides emission and absorption, the effects of dispersion, refraction, and molecular scattering of the light traversing an entirely

¹⁾ For a method of constructing these surfaces we refer to these Proceedings XIII, 1263; or: Physik. Zeitschr. 12, 677, 1911, or: Handwörterbuch der Naturwissenschaften, VII. 830, (1912).

gaseous medium. This is a great physical problem, toward the complete solution of which only the first steps are as yet being made¹⁾; but awaiting the final results of such investigations, we may already attempt to apply our present knowledge of the matter to the interpretation of solar phenomena.

From the astrophysical point of view one of the questions material to the case is what can be presumed about the general radial gradient of the density in the layers we are concerned with?

This subject has been treated very fully and ingeniously, on the basis of thermodynamics, by EMDEN in his book "Gaskugeln." EMDEN arrives at the conclusion already mentioned above, that the fall of the density must be extremely rapid; but the inference is open to doubt, for in his calculations EMDEN presupposes gravitation to be the only radial force acting on solar matter. According to the present state of our physical knowledge, however, we decidedly must admit that on the sun gravitation is counteracted by the pressure of radiation, and by the emission of electrons and perhaps of other charged particles.

Basing on purely theoretical grounds an estimate of the intensity of that counteraction would, for the present, be as rash as denying its existence, but some evidence in favour of its essentiality is given by the fact, that many solar phenomena are much better understood if we assume a radial gradient many times smaller than the one that would correspond to gravitational conditions only. In this connection we would call attention to the puzzling properties of quiescent, hovering prominences. Father FÉNYI, in his interesting discussion of the long series of prominence observations made at Haynald Observatory, Kalocsa²⁾, is very positive in his assertion that several well-established facts concerning quiet prominences can only be accounted for, if in the solar atmosphere gravity is reduced, by certain repulsive forces, to a small fraction (something of the order $1/_{80}$) of its commonly accepted value.

Our hypothesis, that a similar counteraction, opposing the effect

¹⁾ RAYLEIGH, Phil. Mag. [5] 47, 375, 1899.

A. SCHUSTER, Astrophysical Journal 21, 1, 1905.

H. A. LORENTZ, The theory of Elections, Leipzig 1909.

L. NATANSON, Bulletin de l'académie des sciences de Clacovic, Avril 1907, Décembre 1909.

W. H. JULIUS, Physik. Zeitsch 12, S 329 und 674, 1911.

L. V. KING, Phil Trans. Roy. Soc. London, A 212, 375, 1912.

²⁾ Publikationen des Haynald Observatoriums, Heft X, 138, (1911). Cf. also FÉNYI, Ueber die Höhe der Sonnenatmosphäre. Mem. Spettroital. (2), 1, 21, (1912).

of gravitation, prevails throughout the visible layers of the sun, is certainly not less plausible, therefore, than the exclusive hypothesis, usually admitted, which makes gravitation the only effective agent in determining the radial gradient¹⁾.

§ 2. We must now endeavour to conceive the appearance of the sun's edge in a transparent gaseous medium where the pressure varies but slowly along the radius.

As already remarked, SCHMIDT's ingenious optical explanation cannot be adhered to. Nevertheless the principle of ray-curving introduced by that author is extremely suggestive; it leads to the following interpretation of the solar limb, which appears not to encounter similar difficulties.

Let fig. 2 represent an equatorial section of the sun. It can hardly be doubted that besides the gradual, perhaps slow variation of optical density corresponding to the outward decrease of pressure, there are many *irregular optical density gradients* connected not only with the local differences of pressure that accompany the convection currents and solar vortices, but also with the differences of temperature and of composition occurring in the gaseous mixture.

Now, the average magnitude of those irregular gradients of optical density will very probably decrease as we proceed from a level P toward a level Q .

Let us imagine the "irradiation surfaces" to be constructed for a point P_1 of the level P and for a point Q_1 of Q . At the level Q the irregular gradients may in general be so small that rays, leaving it along a tangent Q_1E in the direction of the earth, are hardly ever sufficiently curved to be the continuation of rays coming from within the irradiation surface of Q_1 . This condition will obtain if the average radius of curvature of rays tangent to the level Q is more than,

¹⁾ In the *Astrophysical Journal* 31, p. 166 (1910) Mr. J. A. ANDERSON has criticized the conclusions arrived at in my paper "Regular Consequences of Irregular Refraction in the Sun" (*Proc. Roy. Acad. Amst.* Oct. 28, 1909). His refutation of the idea that refraction might be very momentous in solar physics is entirely founded on the following two assumptions: 1. the photosphere may be represented by a perfectly uniform self-luminous surface, radiating approximately according to the cosine law, and 2. on the sun the weight of a gas is 27.3 times as great as on the earth. I think we may now safely state that the first assumption is contrary to observed facts, and that the second assumption is an unproved dogma, subject to well-founded doubts.

Moreover, a very important point, overlooked by Mr. ANDERSON is, that considerable optical density gradients may result from differences of temperature or of composition, even at uniform pressure.

say, three times as great as the radius of the sphere Q . Then the observer receives little light from Q_1 ; he will consider the level Q to lie outside the solar limb.

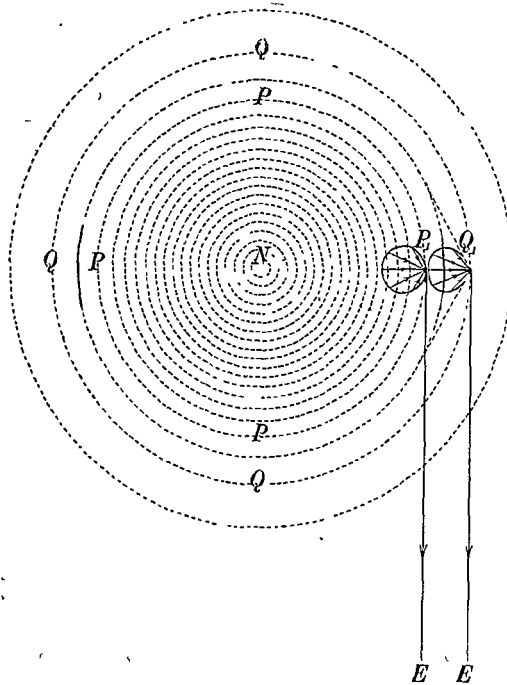


Fig. 2.

If, on the other hand, in a layer P the gradients are so much steeper, that there the average radius of curvature of tangential rays is smaller than, say, one third of the radius of the sphere P , we may expect a sensible fraction of the light that P_1 receives from the interior to get sufficiently deviated in the region surrounding P_1 , so as to proceed toward the earth along the tangent P_1E . The observer will now consider P_1 to belong to the solar disk.

The transition from disk to surroundings will appear abrupt if the minimum distance between levels like P and levels like Q be less than 700 kilometers (one second of arc). This condition is compatible with a rather slow radial pressure gradient, because it only requires that the average radius of curvature¹⁾ $\left(\rho = n : \frac{dn}{ds}\right)$ of rays

¹⁾ "Average radius of curvature" is here used as an abbreviated expression for: "the radius of curvature corresponding to the average value of that radial component of the irregular density gradients, which is directed toward the centre of the sun."

deviated by irregular gradients of optical density be about 9 times greater in Q than in P . (Even a smaller ratio would probably suffice). There will then appear a circular boundary between P and Q , lying in a plane through the sun's centre perpendicular to the line of sight, but there is no particular "solar surface" corresponding to it.¹⁾

In a level P just inside the apparent photosphere the average value of q may still be of the order of magnitude 10^{10} cm. We can easily show that to such curvatures of rays correspond quite reasonable density gradients. For if we suppose hydrogen to be a principal constituent of the visible layers, the average refraction-constant $R = \frac{n-1}{\Delta}$ of the medium may be estimated at 1.5. Putting this value, and $q = 10^{10}$, into the relation²⁾

$$\frac{d\Delta}{ds} = \frac{1}{Rq},$$

we obtain the density-gradient 6×10^{-11} , which means that in two points one kilometer (10^6 cm.) distant from each other the density only differs 0,000006, i.e. 0,5 % of the density of our terrestrial atmosphere. It would be very remarkable indeed, if the general circulation in the sun did not bring along local differences of temperature and of composition sufficient to account for density gradients

¹⁾ At first sight one might be inclined to think that the boundary thus defined has the same radius as SCHMIDT's critical sphere would have. On closer examination, however, the two notions appear to be entirely different. This is clearly brought out with the aid of the following analogous conception. Imagine a spherical mass of liquid (radius R) of constant *average* optical density, and, as a source of light in the middle of it, an incandescent lamp provided with a big globe of milky glass. As there is no radial density-gradient, a critical sphere in the sense of SCHMIDT's theory could not appear in that medium. Let the liquid be a mixture of a solution of common salt and a solution of glycerine in water, both solutions having the same specific weight but different refracting power (cf. Physik. Zeitschr. 11, 59, 1910). If we now suppose that only in the outer spherical shell (radii R and $\frac{3}{4}R$) the solutions are completely mixed, whereas in the inner shell, surrounding the luminous globe, the liquids are only stirred, but still honeycombed with irregular gradients of optical density — the *average* optical density of the shells being the same — then the inner shell will seem to be a self-luminous body. The origin of its boundary is comparable with that of the solar limb according to our theory.

The above interpretation of the photosphere evidently involves an explanation of the reversing layer and the chromosphere as soon as we take account of anomalous dispersion. On this subject, however, we shall not expatiate in the present paper.

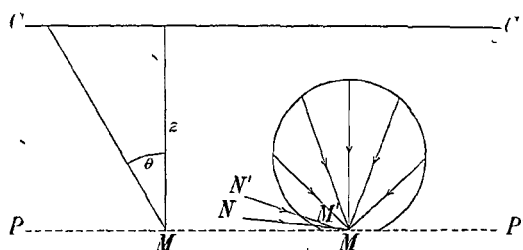
²⁾ Cf. these Proceedings IX, p. 352, 1907.

of that order of magnitude. In a layer, for instance, where the average density does not exceed the density of our own atmosphere at sea-level, a temperature gradient of $1^{\circ}.4$ C. per kilometer is all that would be required.

§ 3. The above dioptrical conception of the photosphere implies the following explanation of the variation of brightness across the disk.

This problem, indeed, may also be expressed as follows: what is the cause of the fact, that the *irradiation surface* of a point M , lying somewhere in or near the "photospheric level", has that particular shape (different according to the selected wave-length), which direct observation assigns to it?

Let PP' (Fig. 3) represent a part of the photospheric level, CC'



of another level lying so much deeper, that there the solar matter is dense enough to emit light giving a continuous spectrum.

Although the medium surrounding M be a mixture of selectively absorbing gases, transparent to the greater part of the spectrum, that transparency is not absolute. *Molecular scattering* (RAYLEIGH)¹⁾ weakens a *direct beam* according to the law

$$I = I_0 e^{-sz}, \text{ in which } s = \frac{32\pi^3(n-1)^2}{3\lambda^4 N};$$

but if the source of light be an incandescent surface CC' , radiating the energy I_0 per square unit, and if the diffused light itself be taken into consideration, the energy emerging per square unit from PP' will (as found by SCHUSTER)²⁾ be expressed thus:

$$I = I_0 \frac{2}{2 + sz}.$$

¹⁾ RAYLEIGH, Phil. Mag. [5] 47, 375, (1899).

²⁾ SCHUSTER, Astroph. Journ. 21, 1, (1905).

ABBOT, in his valuable book "The sun", (1911), also introduces molecular scattering as a principal agent in producing the appearance of the photosphere.

We are aware that this formula does not hold exactly for non-homogeneous media, nor for oblique directions when simply replacing z by $z \sec \theta$; but as a first approximation we shall put

$$J = J_0 \frac{2}{2 + sz \sec \theta},$$

where J and J_0 now bear on units of surface located in the layers PP' and CC' respectively, and taken perpendicular to the direction considered. Supposing J_0 to be independent of direction, we find that J decreases as θ increases, in agreement with the characteristic of the irradiation surface¹⁾.

One of the causes why the latter equation cannot be expected to represent the conditions completely is, that it does not allow for possible incurvation of the direct beams passing through the medium. If θ approaches the value 90° , our formula makes J tend toward zero, whereas in reality the brightness at the limb only falls to values between $0,13 J_{\theta=0}$ and $0,30 J_{\theta=0}$ with different colours.

Now, it is evident that refraction by the irregular density gradients at once accounts for the discrepancy; indeed, a beam reaching M along NM (θ nearly $= 90^\circ$) might have been turned into that direction out of another direction $F'M'$ for which θ has a smaller value, so that J will have a greater value than the one corresponding to the formula. It is exactly this process on which our explanation of the sun's edge was based.

If, therefore, we consider both scattering and irregular refraction effects, the conclusions to which the theory leads are compatible with the observed shape of the irradiation surface, or with the law according to which the average intensity of a given kind of light decreases from the centre toward the limb of the solar disk.

The agreement also prevails when kinds of light of different wave-lengths are considered. Let us distinguish between, e.g., red and violet, by introducing the subscripts r and v .

¹⁾ A full comparison of the theoretical with the observational irradiation surfaces for different wave-lengths will be published at a later date. If $2 \cos \Theta$ may be neglected as compared with sz , the expression becomes

$$J = J_0 \frac{2}{sz} \cos \theta,$$

the equation of a sphere, tangent to the photopheric level in M . The irradiation-surface, as constructed with the values for violet light taken from H. C. Vogel's well-known table (Ber. der Berl. Akad. 1877, p. 104), is in its main part strikingly similar to such a sphere.

At the center of the disk ($\theta = 0$) we have between the intensities of red and violet light the proportion

$$p_0 = \frac{J_r}{J_v} = \frac{J_{o,r}}{J_{o,v}} \cdot \frac{2 + s_v z}{2 + s_r z},$$

in which, according to RAYLEIGH's formula, $s_v > s_r$ (if cases of anomalous dispersion be excluded, so that the disparity between n_v and n_r may be neglected).

At a point, corresponding to the angle θ , we have

$$p_\theta = \frac{J_{o,r}}{J_{o,v}} \cdot \frac{2 + s_v z \sec \theta}{2 + s_r z \sec \theta}.$$

The second factor of p_θ is greater than unity, and p_θ is greater than p_0 . This means, that the longer waves preponderate as we move from the center of the disk toward the limb. With increasing values of $\sec \theta$, p_θ approaches the limit

$$p_{\infty} = \frac{J_{o,r}}{J_{o,v}} \cdot \frac{s_v}{s_r} = \frac{J_{o,r}}{J_{o,v}} \cdot \frac{\lambda_r^4}{\lambda_v^4};$$

this proportion, however, will be more or less modified by irregular refraction.

§ 4. Taking all in all, the above theory of the photosphere thus appears to account for the sun's edge, and for the principal features of the results of VOGEL's well-known spectrophotometric measurements.

It implies at the same time an interpretation of the *granular structure* of the solar disk as an effect of refraction. If ANDERSON ¹⁾ and other astrophysicists were right in assuming the irradiation surface of a point M near the photospheric level to be a hemisphere sps_1 (Fig. 1 p. 266), irregular gradients of optical density could not produce any sensible disturbance in the uniform brightness of the disk, except in special cases. But their assumption certainly is erroneous; the average intensity of the light passing through M varies considerably with the value of the angle θ ; so the irregular refraction of the light must necessarily result in variegation of luminosity.

Waves that undergo anomalous refraction will of course be deviated to a higher degree in the same gradients. Following out this line of thought, we arrive at explanations of spectroheliograph results ²⁾, on which we shall not now insist.

A few remarks may be added in connection with the sun-spot

¹⁾ Astroph. Journal **31**, 166 (1910).

²⁾ Cf. Astroph. Journal, **21**, 278, 1905; **28**, 360, 1908; **31**, 419, 1910.

hypothesis suggested in 1909¹⁾. A spot was supposed to be a region where, from a central minimum outward, the optical density increases with a gradually decreasing gradient. If sun-spots are solar vortices, such conditions are very likely to obtain. It was then argued that, when a similar structure is traversed by the light from an extensive source radiating, as the photosphere does, with intensities decreasing from the center toward the limb, refraction must exactly produce the characteristic optical features observed in a spot: an umbra surrounded by a penumbra. Taking anomalous dispersion effects into consideration, one is led by the same argument to an explanation of the principal properties of the spot-spectrum. Lately we succeeded in realizing, in the laboratory, the formation of a typical "sun-spot" by refraction of light in a whirling mass of gas, and could witness several phenomena, rather closely resembling the appearances produced by the real solar objects. A description of those experiments, together with a discussion of their possible bearing on several spot-problems (e.g. on the apparent effect of the earth on the formation and growth of sun-spots) must be deferred to a separate paper.

We now only wish to emphasize the fact that the above conception of sun-spots naturally fits in with our dioptrical explanation of the photosphere. The levels where vortex-motion should occur so as to produce the appearance of a spot, will be found somewhere between spheres corresponding to PP and QQ of our Fig. 2. The conditions in a spot need not differ very much from those obtaining in the surrounding regions. Their chief characteristics are: 1. the rotary motion, which determines a magnetic field and a systematic arrangement of density gradients (which need not be steeper than the average irregular gradients otherwise present in the same levels), and 2. the differences of temperature and of composition connected with the special form of circulation.

Summary.

Various views concerning the nature of the photosphere are criticized, and a new dioptrical interpretation of several photospheric phenomena is proposed.

¹⁾ Proc Roy. Acad. Anst 12, 273, 1909; Physik. Zeitschr. 11, 62, 1910.