PROF. ZOELLNER ON THE SUN'S TEMPERATURE AND PHYSICAL CONSTITUTION[*]

AMONG the characteristic forms of the protuberances[†] the observation of which the spectroscope with widened slit has rendered possible at all times, is to be found a not inconsiderable number of such, whose appearance at once conveys the conviction to every impartial observer that we have here to deal with vast eruptions of incandescent hydrogen masses.

It is probably impossible, without quitting the range of known analogous occurrences and at the same time the conditions explanatory of cosmical phenomena, to assume any other cause of these eruptions than the *difference of pressure* of the issuing gas in the interior and on the surface of the sun. The possibility of such a difference of pressure presupposes, necessarily, the existence of a separating layer between the inner and outer masses of hydrogen, the latter of which, as is known, form an essential constituent of the sun's atmosphere.

The assumption of the existence of such a separating layer is, at first sight of the above-mentioned protuberance phenomena, so cogent that it even forces itself as undeniable upon observers who, like Respighi, do not hold it to be improbable that electrical forces could be the cause of such eruptions.

Keeping, however, to the more simple and therefore more natural assumption of a difference of pressure, we have to deal with a phenomenon which, on the application of the mechanical theory of heat and gases, is capable of yielding most important information as to the temperature and physical constitution of the sun.

For perfect gases the mechanical theory infers from its premises,—firstly, the law of Mariotte and Gay-Lussac; secondly, the constancy of the relation of the specific heats at constant volume and constant pressure.

This constant, therefore, when determined according to known methods for a definite gas, must, from the point of view of the mechanical theory of gases, be considered, similarly to the atomic weight of a body, as invariable, and must on no account be placed in the category of other empirical constants, such as the conducting power of bodies for heat, or the co-efficient of expansion of solid and liquid bodies, &c. These constants only hold good within those limits within which they are determined by observation, and lose their significance when employed far beyond those limits.

Under this supposition I consider the eruptive protuberances as a phenomenon of the efflux of a gas from one space into another, the pressure in both spaces during the discharge being assumed constant, and neither a communication nor an abstraction of heat as taking place.

Let A be the heat-equivalent of the unit of work,
v the velocity of efflux of the gas in the plane of the opening,
g the intensity of gravity on the sun,
x the relation of the specific heats of the gas at constant pressure and constant volume,
c the specific heat of the gas at constant volume referred to an equal weight of water,
t_i the absolute temperature of the gas in the inner space, from which the efflux takes place,
t_a the absolute temperature of the issuing gas in the plane of the discharge opening,
p_i the pressure of the gas in the inner space,
p_a the pressure in the plane of the discharge opening.

Then, according to the dynamical theory of heat, we have, under the assumptions which have been made, the following two relations[‡] between these nine magnitudes :—

$$A \frac{v^2}{2g} = xc\left(t_i - t_a \right) \qquad (1)$$

$$\frac{t_i}{t_a} = \left(\frac{p_i}{p_a} \right)^{\frac{x-1}{x}} \qquad (2)$$

Further, let a_1 be the mean height of the barometer in metres of mercury,
ρ the density of the gas under consideration at the temperature of melting ice, and under the pressure a_1 on the earth's surface,
σ the density of the gas contained in the inner space under the pressure p_i, and at the absolute temperature t_i,
a the coefficient of expansion of the gas for 1° C.

Conformably to the law of Mariotte and Gay-Lussac, we then have also the following relation :—

$$\sigma = \frac{\rho}{a_1 a} \frac{p_i}{t_i} \qquad (3)$$

The pressure p_a in the plane of the discharge opening may, under the suppositions made, be considered as identical with the pressure which the atmosphere of the sun exercises at the *niveau* of the above-mentioned separating layer, *i.e.*, at its base.

Let, in this case,
p_a be the pressure at the base of the atmosphere,
h a certain height above the base,
p_h the pressure at this height,
t the absolute temperature in the atmosphere, which, in consequence of insufficient knowledge of the law of temperature is assumed to be everywhere constant,
g the gravity of the sun at the base of the atmosphere,
r the radius of the separating layer,
ρ_1 the specific gravity of mercury at the temperature of melting ice,
g_1 the intensity of gravity on the earth's surface,
a_1 the mean height of the barometer,
ρ the density of the gas composing the atmosphere at the temperature of melting ice, and under the influence of the quantities g_1 and a_1;

we then obtain, by a known method of deduction, the following relation,

$$\text{log. nat. } \frac{p_a}{p_h} = \frac{\rho g r h}{\rho_1 g_1 a_1 a t \, (r + h)} \qquad (4)$$

In order to combine this with the three previous equations, a double assumption must be made :

First, that the essential constituent of the sun's atmosphere, which produces the pressure p_a, consists of the same gas as escapes from the interior of the sun during eruptive protuberances.

Secondly, that the absolute temperature t of the atmosphere, may be considered as essentially agreeing with the absolute temperature at the *niveau* of the opening during the discharge.

Having regard to the object of the present memoir, I consider the admissibility of the first assumption as sufficiently established by observations, since the discovery of the so-called chromosphere has given the proof that the whole surface of the sun is surrounded by an atmosphere of hydrogen of very considerable extent.

The correctness of the second assumption I infer *from the luminosity of the base of all eruptive protuberances not differing to any extent from that of the chromosphere.* When it is considered that the constant mean temperature t in Formula (4), which, in consequence of the want of knowledge of the law governing the decrease of temperature, is substituted for the temperatures falling with the height h, evidently must correspond to a layer near the base,[*] this temperature becomes at the same time approximated to that belonging to the outer surface of the separating layer.

By virtue of the first assumption, the value ρ in Formula (4)

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[*] *T. Zöllner. Ueber die Temperatur und physische Beschaffenheit der Sonne.* Berichte Kön, Sächs, Gesellschaft der Wissenschaften. Sitzung am 2 Juni, 1870.

[†] The forms of the protuberances may be divided into two characteristic groups—into the vapour- or cloud-like and into the eruptive formations. The preponderance of the one or the other type appears partly to be dependent on local conditions on the surface of the sun, partly on the time, so that at particular periods the one, at others the other, type preponderates. The striking resemblance of the cloud-like formations to terrestrial clouds is readily explained, when it is considered that the forms of our clouds are due, not to the particles of water suspended in them, but essentially to the nature and manner in which the differently heated and agitated masses of air are spread out. *The particles of aqueous vapour are, in terrestrial clouds, simply the material by means of which the above-mentioned differences between the masses of air are rendered evident to us. The glow of the incandescent masses of hydrogen is the cause of the visibility of the clouds of the protuberances.*

[‡] Zeuner, Grundzüge der mechanischen Wärmetheorie. 2 Aufl 1866, p 165.

[*] With regard to the increasing density of the layers of air towards the base, the temperature introduced into Formula (4) must, apart from the special law for the decrease of temperature, always agree with the temperature of a layer which lies deeper than $\frac{h}{2}$ This difference, which, as a simple calculation shows, is in general a very considerable one, seems to me to be entirely disregarded in the barometrical estimation of heights, in which, as is known, the mean temperature of the two stations is made use of, and to give a simple explanation of certain periodical phenomena which have lately been urged.

becomes identical with the analogous one in (3), and, in consequence, of the second

(2.)

$$t = t_a$$

The theoretical foundations and essential assumptions necessary for the treatment of the phenomena in question on the sun's surface having been explained, a reconstruction and simplification of the above equations, more suitable to the object in hand, may well follow.

If H denote the height to which a body with the initial velocity v on the sun's surface is hurled up in a vertical direction, then, taking the diminution of gravity into account, we have:

$$v^2 = 2g\mathrm{H}\frac{r}{r+\mathrm{H}}$$

or,

$$\frac{v^2}{2g} = \frac{r\mathrm{H}}{r+\mathrm{H}}$$

This value substituted for $\frac{v^2}{2g}$ in Equation (1) gives:

$$t_i = \frac{r\mathrm{HA}}{xc\,(r+\mathrm{H})} + t_a;$$

or taking $\frac{r\mathrm{HA}}{xc\,(r+\mathrm{A})} = a$, and, according to our assumption, $t_a = t$, we obtain the following for Equation (1):

$$t_i = a + t \qquad \text{(I.)}$$

Further, let

$$\frac{x-1}{x} = \frac{1}{q}$$

$$\frac{\rho}{a_1 a} = b$$

$$\frac{g}{g_1 \rho_1} = m$$

The Equations (2) (3) (4) become then converted into the following:

$$\frac{t_i}{t} = \left(\frac{p_i}{p_a}\right)^{\frac{1}{q}} \qquad \text{(II.)}$$

$$\sigma = b\frac{p_i}{t_i} \qquad \text{(III.)}$$

$$p = p_h e^{bm\frac{rh}{(r+h)t}} \qquad \text{(IV.)}$$

In addition there is obtained from these four equations by elimination the following:

$$\sigma = \frac{b\,p_h}{a+t}\left(\frac{a+t}{t}\right)^{q} e^{bm\frac{rh}{(r+h)t}} \qquad \text{(V.)}$$

This equation, of course, expresses the density, σ, of the compressed mass of gas only as a function of the three magnitudes p_h, h, and t; if, therefore, under the assumptions made, three out of the four values considered can be determined by observation, either positively or within certain degrees, the fourth can then be determined. And in fact, partly by spectroscopic, partly by other, observations, fixed extreme values can be obtained for the magnitudes σ, p_h, and h, so that thus a limit for t, that is to say, for the outer hydrogen atmosphere in the neighbourhood of the incandescent liquid separating layer, is also obtained. This value substituted in Equation (1) the value of H being known, gives then at once a value for the inner temperature t_i, and from (III.) and (IV.) fixed values for p_i and p_a can be obtained with equal ease.

(3.)

Now to proceed, however, to the discussion of numerical values, I will commence with Formula (I.)

The lowest value which can be attached to t is evidently 0. We then obtain for the inner temperature t_i the minimum value:

$$t_i = a = \frac{r\mathrm{HA}}{xc\,(r+\mathrm{H})} \qquad (5)$$

Having regard to the extreme tenuity, and therefore slight resistance, of the atmosphere even at a very moderate distance from the sun's surface, the value of H may, for the sake of simplicity, be put as equal to the mean height of the eruptive protuberances. A more detailed discussion of the conditions under which this is allowable will be given later.

Protuberances three minutes high are not of very rare occurrence; to keep, however, as close as possible within the limit of an estimation of mean value, I will assume H to be only 1· minutes.

Adopting the metre and centigrade degree as units, I take the heat equivalent A as $\frac{1}{424}$. The product xc is, according to the latest researches of Regnault, for hydrogen 3·409. According to Dulong, the value of x for hydrogen is 1·411.

The numerical value of r requires a somewhat more detailed discussion. It is, according to the preceding, the radius of the separating layer from which the protuberances break forth. There then arises the question, whether this value agrees with that of the sun's radius; that is, whether this separating layer coincides or not with the portion of the sun's luminous disc, which we have made use of for our measurements.

The late researches of Frankland and Lockyer, St. Claire, Deville, and Wüllner have proved that the discontinuous spectrum of hydrogen and other gases can, by increase of pressure, be converted into a bright luminous and continuous spectrum, the bright lines of the discontinuous spectrum passing through a series of very characteristic changes, on the pressure being gradually raised, which principally, as for instance by the line Hβ, consist in a widening out and increasing indefiniteness of outline.

These changes permit within certain limits an estimation of the intensity of the pressure on the spot in question, and Frankland and Lockyer have already hazarded such conclusions. They arrive at the result "that at the lower surface of the chromosphere the pressure is very far below the pressure of the earth's atmosphere."

The researches of Wüllner, I believe, allow even the conclusion *that the pressure at the base of the chromosphere, or at the outer edge of the sun's luminous disc, must lie between* 50*mm. and* 500*mm. of a mercury barometer on the earth's surface.*

According to this, the presence of dark lines on a continuous ground in the sun's spectrum no longer compels the conclusion that this continuous spectrum is caused by the incandescence of a solid or liquid body. The continuous spectrum can equally well be considered as produced by the incandescence of a strongly compressed gas.

Wüllner has, in fact, proved this for the sodium line; for in his account of the above-mentioned researches he remarks:—

"At a pressure of 1230mm. the maximum at H_a recedes still further; the whole spectrum is truly dazzling; the sodium lines appear as beautiful dark bands;* consequently, the light of hydrogen gas is sufficiently intense to produce a Fraunhofer's line in a sodium atmosphere—a proof that the light of an incandescent solid is not necessary."

From this it follows that the radius of the visible portion of the sun's disc need not be considered as identical with that of the supposed separating layer, but that the latter probably must be looked upon as situated beneath the layer where, through increased pressure, the spectrum of the hydrogen atmosphere becomes continuous. This view is strongly supported by a consideration of the phenomena of the sun's spots.

However different the views as to the nature of the sun's spots may be, almost all observers agree that the nuclei of the spots must lie deeper than the surrounding portion.† Partly from direct (De La Rue, Stewart, Loewy), partly from indirect (Faye) observations the depth is assumed to be about 8".‡

If, then, the nuclei of the sun's spots are considered as scoriaceous products of a local cooling down on an incandescent liquid surface and the penumbra as clouds of condensation, which at a certain height crown the coasts of these slag islands, the simplest assumption is, that the (according to this theory) necessarily liquid surface is identical with the surface of the separating layer in question from which the protuberances break forth. The radius r of this surface therefore, the observed semi-diameter of the sun being expressed in seconds, would be approximately—

$$r = R - 8''$$
$$r = 15'52''$$

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* In consequence of the high temperature in the tubes, sodium volatilises out of the glass. At a pressure of 1000mm. the sodium lines are still luminous.

† Spoerer says, however, "We consider the spots to be cloudlike formations far above the luminous surface of the sun's body. The penumbra is simply a collection of smaller spots, through the spaces between which the luminous surface is visible above which the spot is situated." (Comp. Pogg. Ann. lxxviii. 270.)

‡ From calculation of Carrington's observations Faye finds this depth t be ·005 — ·009 of the sun's radius. (Comp. Rend. lxi. 270.)

Accepting Hansen's determination of the mean parallax of the sun, 8"·915 we obtain

$$r = 680,930,000 \text{ metres};$$

consequently,

$$8'' = 5,720,500 \text{ metres}.$$

We have accordingly, in order to get at a numerical estimation of the absolute minimum temperature in the space from which an eruption 1·5 minutes high breaks forth, to introduce the following values into Formula (5):—

$$\begin{aligned} r &= 680,930,000 \\ H &= 64,370,000 \\ A &= \tfrac{1}{424} \\ xc &= 3{\cdot}409 \end{aligned}$$

It is then found,

$$t_i = 49,690^\circ$$

If for *H* a double so high a value be taken, viz., the by no means rarely observed height of eruption of three minutes, a minimum value

$$t_i = 74,910^\circ$$

is obtained.

The question arises here, however, are we at all authorised to introduce the extreme observed heights of protuberances at once into our formulæ as values of *H*, in which *H* denotes the height to which a body hurled up from the surface of the sun would rise if there were no resistance. If in fact, and it is conclusively proved by observation, we are dealing with ascending masses of nascent hydrogen, the ascent can also take place according to the Archimedean principle, similarly to the heated masses of air, which are thereby lighter than the surrounding portions, issuing from a chimney. It is however at once manifest that both causes of motion with regard to the time in which the masses reach a certain height are essentially different. Without entering more specially into this circumstance, it is clear that the time which, in virtue of the Archimedean principle, a protuberance requires to reach a certain height *H*, must under all circumstances be greater than the time expended by a body thrown up with a certain initial velocity, and without resistance to the same height *H*.

Consequently, a possibly correct observation of the time which an ascending protuberance requires to attain a certain height may serve as a criterion, whether we have to regard this height as the result of the first cause or not, and only in the former case can this height be made use of as an integrating constituent in the above formulæ.

According to the assumptions made, the exit opening (Auströmungsöffnung) of the protuberances is situated in the incandescent liquid separating layer at a depth $h = 8''$ below the visible border of the sun's disc. The height of a protuberance from the plane of the exit-opening was expressed above by *H*.

Let now:

$\tau =$ the time occupied by the protuberance in passing from the opening to the height *H*,

τ_1 the time occupied by the protuberance in passing from the height *h*, i.e., from the outer border of the photosphere, to the height *H*,

v, the velocity at the exit opening,

v_1, the velocity at the height *h*.

Then assuming the first cause, and disregarding the decrease in the intensity of gravity (g) we obtain the following equations:—

$$\tau = \sqrt{\frac{2H}{g}} \qquad \tau_1 = \sqrt{\frac{2(H-h)}{g}}$$

$$v = \sqrt{2gH} \qquad v_1 = \sqrt{2g(H-h)}$$

Then making

$$\begin{aligned} H &= 64,370,000 \text{ m.} \\ h &= 5,722,600 \text{ m.} \\ g &= 274{\cdot}3 \text{ m.} \end{aligned}$$

we have

$$\tau = 11 \text{ min. } 25 \text{ sec.} \qquad \tau_1 = 10 \text{ min. } 54 \text{ sec.}$$

$$v = 187,900 \text{ mm.} = 25{\cdot}32 \text{ geogr. miles.}$$

$$v_1 = 179,400 \text{ mm.} = 34{\cdot}17 \text{ ,, ,,}$$

If, therefore, we observe a velocity of ascent of the quoted magnitude, we are entitled to make use of the height obtained by the protuberance in the above time in our equations. I have often observed such a rapidity of evolution, and annex a sketch of a protuberance, the observed velocity of ascent of which agreed well with the value above found.

With respect to the enormous initial velocities of motion, Lockyer has by his magnificent observations of the change in refrangibility of the light arrived directly at results of exactly the same order.

Lockyer,* during the short period of observations of this nature, found 40 and 120 English miles per second as maximum values for the velocities of vertical and horizontal gas currents in the chromosphere. The above values expressed in English miles gave,

$$v = 123{\cdot}1 \text{ English miles}, \quad v_1 = 117{\cdot}7 \text{ English miles},$$

and agree, therefore, with Lockyer's values.

But movements of such magnitude pre-suppose, necessarily, according to the mechanical theory of heat, differences of temperature of 40,690° C. for hydrogen.

We shall, accordingly, be able to ascertain the actual temperature if we can succeed in determining the temperature, *t*, of the outer hydrogen atmosphere at a certain spot. Why this temperature is taken as agreeing approximately with the temperature in the vicinity of the exit opening has already been discussed.

(4.)

An extreme value for *t* is obtained by discussion of Eq. v. This equation is:—

$$\sigma = \frac{b p_h}{a+t}\left(\frac{a+t}{t}\right)^q e^{\,b m \frac{r h}{(r+h) t}}$$

The density σ of the included mass of gas is in this expressed as function of the three magnitudes p_h, *h* and *t*. I shall now show that σ must not exceed a certain value, by which the value of *t* is also indirectly fixed within a certain limit, since the magnitude $p_h + h$ are determined within certain limits by the observations already quoted.

Stress has already been laid upon the fact that the explanation of the eruptive protuberances necessarily requires the assumption of a separating layer which separates the space from which the eruptions break forth from that into which they discharge. Only by such a separating layer are the requisite differences of pressure made possible.

With regard to the physical constitution of the separating layer the further assumption must necessarily be made, that it consist of a substance other than in a gaseous condition. It can therefore only be liquid or solid. If, having regard to the high temperature, we exclude the solid condition, there then only remains the assumption, that the separating layer consists of *an incandescent liquid*.

With respect to the inner masses of hydrogen bounded by this layer, two assumptions seem on superficial considerations possible, viz.:

1. The whole interior of the sun is filled with incandescent hydrogen: the sun therefore resembles a vast hydrogen bubble surrounded by an incandescent liquid envelope.

2. The hydrogen masses which burst forth during the eruptions are local accumulations in vesicular spaces, which form in the surface layers of an incandescent liquid mass, and which break through their envelope in consequence of the increasing tension of the included gas.

Under the first assumption a stable equilibrium could only exist when the sp. gr. of the liquid boundary layer is lower than that of the layer of gas directly beneath. The density of a ball of gas, the particles of which obey the laws of Newton and Mariotte, increases, however, from the exterior to the interior, consequently the sp. gr. of the separating layer must necessarily be lower than the mean sp. gr. of the sun; if, on the other hand, the mean sp. gr. of the sun be taken as the extreme sp. gr. of the liquid separating layer, this value would at the same time involve the assumption that all the deeper layers, therefore the layer of gas immediately below, possess the same sp. gr.

The interior of the sun would then no more consist of a gas, but of an incompressible liquid. All these properties are evidently a necessary consequence of the assumption, that the sp. gr. σ of the compressed mass of gas which breaks forth during eruptions attains its maximum value, viz., that of the sun's mean sp. gr.

Then in this case the first assumption is changed into the second, viz., that the sun consists of an incompressible liquid, in which local accumulations of incandescent hydrogen masses form near the surface, which on the necessary differences of pressure burst forth from the hollows containing them as eruptive protuberances.

However small the hollows may be assumed to be in special

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* Proceedings R.S. No. 115 (1869). Comp. Rend. lxix. 123.

cases, the sp. gr. of the enclosed gas masses must not be taken as higher than that of the enclosing liquid, since otherwise the compressed gas masses would, in virtue of the Archimedean principle, sink down into the interior of the sun.

The sp. gr. of the sun is, according to the latest determinations,

$$1{\cdot}46.$$

Substituting this value for σ and for a (in Formula V.), the above found value 40,690, also for h the value 8″ in metres, we obtain for the extreme values $p_h = 0{\cdot}050$ m. above given, the following values of t:

$$\text{for } p_h = 0.500 \text{ m.} \qquad t = 29{,}500^\circ$$
$$\text{for } p_h = 0{\cdot}050 \text{ m.} \qquad t = 26{,}000^\circ;$$

therefore in mean, $t = 27{,}700^\circ$.

On differentiating Equation (5) by t, the differential quotient $\frac{d\sigma}{dt}$ is negative. From this follows that the values found above for t are also minimum values.

From the mean value of t for the temperature of the sun's atmosphere the value of p_h is found $= 0{\cdot}180$ m. These values will be those made use of in the following calculations.

It may be noticed in connection with the high numbers obtained for the temperature values, that they are about eight times higher than the temperatures of combustion of a mixture of detonating gas as found by Bunsen, and that iron must permanently exist in a gaseous condition in the sun's atmosphere.

With the above value for $t = 27{,}700^\circ$ we obtain from Formula (I.) for the inner temperature

$$t_i = 68{,}400$$

substituting these two values of t and t_i in Formula (II.) we have

$$\frac{p_i}{p_a} = 22{\cdot}1$$

i.e., the pressure in the interior of the space from which the protuberances break forth is 22·1 times greater than the pressure on the surface of the liquid separating layer. Further substituting the value for t in Formula (IV.) and assuming as before the value of h to be 8″, we have

$$\frac{p_a}{p_h} = 766{,}000$$

as the relation of the pressure on the fluid surface of the sun to the pressure at the height h, where the hydrogen spectrum, in consequence of the pressure, begins to become continuous.

Substituting for p_h the above value of 0·180 m. mercury, we have

$$p_a = 184{,}000 \text{ atmospheres,}$$

and consequently for $p_i = 4{,}070{,}000$,,

If the depth be calculated at which in the interior of the liquid mass of the sun which has a sp. gr. of 1·46, and simply as the result of the hydrostatic pressure, this maximum pressure of p_i would be attained, it is found that this would occur at a depth of 139 geographical miles below the surface, *i.e.*, at a depth of about 1·46 arc seconds, or $\frac{1}{658}$ of the sun's semidiameter.

Even if the liquid condition be put quite out of question, and, under assumption of a much larger atmospheric envelope of hydrogen, the depth in it be calculated, at which the atmospheric pressure becomes equal to the inner pressure p_i, it is found that even assuming a temperature of 68,400°, that depth is only 27″ below the visible edge of the sun's disc, or about $\frac{1}{36}$ of the sun's apparent semidiameter.

This circumstance shows how rapidly the pressure must increase towards the interior of the sun's body, and thus justifies the assumption that in the interior of the sun, even at such high temperatures, the permanent gases, for example, hydrogen, can only exist in an incandescent liquid condition.

(5.)

A surprising result is obtained if, under the assumption of a nitrogen or oxygen atmosphere of equal weight and temperature to the hydrogen atmosphere above considered, the pressure be calculated which is reached in those atmospheres at heights at which the hydrogen spectrum commences to become continuous. If at a depth of 8″ below the visible edge of the sun's disc, *i.e.*, at the riwean of the supposed separating layer, the pressure of the three atmospheres of hydrogen, oxygen, and nitrogen be assumed as equal, and that $p_a = 184{,}000$ atmospheres, a value which from the above, corresponds to the assumed value of p_h. The following values are obtained for the pressures at the temperature above found $t = 27{,}700^\circ$ on the surface of the sun's *visible* disc in the three atmospheres :—

Hydrogen $p_h = 180$ millimetres.
Nitrogen $p_h = 323\frac{1}{1078}$,,
Oxygen $p_h = 124\frac{1}{1088}$,,

It follows from these that, the assumptions made, the quantities of the two latter gases are, in proportion to the quantity of hydrogen in that layer in which the spectrum of the latter commences to be continuous, infinitely small. This would, as is evident, also be the case if the weights of the two atmospheres were assumed to be many million times greater, although having regard to the specific gravity, a 14-times smaller weight of nitrogen and a 16-times smaller weight of oxygen would suffice, in order that under the assumed conditions the density of these two gases should coincide at the base with that of hydrogen.

According to our former considerations, the sun's mean specific gravity would also in this case have to be assumed as the maximum value of the density at the base of these atmospheres, and it is easy to calculate, with the help of Formula 3, and the known specific gravities of oxygen and nitrogen, how high the weights of these two atmospheres would have to be assumed in order to attain this maximum value.

As result is obtained, that the weight of the oxygen atmosphere could only amount to ·56, that of the nitrogen atmosphere to ·64 of the weight of the existing hydrogen atmosphere.

If therefore the simultaneous existence of these three gases on the sun's surface be assumed, and the influence of atmospheric motion be disregarded, the rays emitted by the continuous spectrum of the hydrogen layers would, on their path to our eyes, pass through so small a number of incandescent nitrogen and oxygen particles, that the absorption caused thereby is a vanishing one, and therefore, as is in fact the case, the presence of oxygen and nitrogen in the sun's spectrum could not be demonstrable by dark lines.

Although the motion of the gases is active in lessening the differences just considered, the existence of the chromosphere proves clearly the slight influence of this action in consequence of the great intensity of gravity, and the considerable height of the layer considered (compare Formula 4).

In order, however to explain through the circumstance indicated the absence of lines in the sun's spectrum of two bodies of such universal distribution on the earth as nitrogen and oxygen, the very slight emissive power of the permanent gases in proportion to that of volatilised bodies must also be taken into consideration. If the emissive power of different gases at the same temperature for rays of the same refrangibility be referred to equal very minute weights of these gases,* the before-quoted experiment of Wüllner's, in which the small amount of sodium volatilised in the Geissler's tube emitted more light than the hydrogen gas under a pressure of 1,000mm., gives a beautiful proof of the extraordinary difference of emissive—and consequently according to the theorem of Kirchhoff of absorptive—power of different gases at the same temperature. Only by consideration of this circumstance is the contradiction removed, which could be deduced against the above explanation of the absence of nitrogen and oxygen lines from the fact that in the sun's spectrum the lines of bodies are present whose vapour densities, as a consequence of their simple relation to the atomic weights, must be much higher than the density of oxygen and nitrogen.

From these considerations, partly directly and partly indirectly through a longer series of conclusions, a detailed exposition of which I reserve for another occasion, the following result :—

1. From the absence of lines in the spectrum of a star shining in its own light, the absence of the corresponding element must not be inferred.

2. The layer in which the reversal of the spectrum occurs is different for each element—the higher the vapour density, and the lower the emissive power of the element, the nearer it is situated to the centre of the star.

3. For different stars, under otherwise similar conditions, this layer lies the nearer to the centre the greater the intensity of gravity.

4. The distances of the reversing layers of the separate elements, both from the centre of the star and from each other, increase with an increase of temperature.

5. The spectra of different stars are under otherwise similar conditions the more rich in lines, the lower their temperature and the greater their mass.

6. The great difference of intensity of the dark lines in the sun's spectrum and other fixed stars does not depend only on the differences of absorptive power, but also on the depths at which the reversal of the respective spectra takes place.

In conclusion, I would offer a few remarks on the application of the observations carried out on rarefied gases to the heavenly bodies. Lecoq de Boisbaudrau* has recently pointed out, with

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* Compt. Rend. lxx. p. 1091

reference to Wüllner's investigation on the variability of spectra at different pressures and temperatures, that the results obtained must only be applied with the greatest care to the conditions of pressure of the sun's atmosphere, as the changes in the spectra are due far more to temperature than to pressure. But even under the assumption that this conjecture should become verified by special experiments, this circumstance would influence the results brought forward in this communication but in a slight degree. For the nature of the function (Formula 5) which served us in determining the temperature of the atmosphere is such that the pressure p_h under which the hydrogen spectrum becomes continuous may be varied within very wide limits without thereby causing any considerable alterations of the requisite temperature. Thus it was shown above that, by introducing the extremes of the pressure assumed which were in the proportion of 1 : 10, the temperature values resulting were only in the proportion of 1 : 1·5.

Nevertheless, the separation of the influences which pressure and temperature exercise on the nature of the spectrum of luminous gases must be regarded as a problem the solution of which is of the highest importance for astrophysics.

THE BRITISH ASSOCIATION

SECTIONAL PROCEEDINGS

SECTION A.—MATHEMATICAL AND PHYSICAL SCIENCE

Rainfall: its Variation with Elevations of the Gauge.—Mr. Charles Chambers, F.R.S. The fact is well known to meteorologists that the quantities of rain received in gauges placed at different heights above the ground diminish as the elevation of the gauge increases. Several attempts have been made to explain this phenomenon, but none of them are so satisfactory as to discourage the search for other causes that may contribute substantially or mainly to its production. Hence the submission for the consideration of the British Association of this further attempt. One of the principal causes of rain is undoubtedly the transfer, effected by winds, of air charged with moisture in a warm damp district to a colder region, where the vapour it contains is partially condensed. The temperature of the lower as well as of the higher horizontal strata of the atmosphere being reduced by this transfer, it may fairly be inferred that condensation of vapour may also occur in the lower as well as in the higher horizontal strata. The rain caught by a gauge at any given elevation will therefore be the sum of the condensations in all the strata above it, and thus the lower a gauge be placed the greater will be the quantity of rain received by it. Again, it is known by observation, that there is at all times a greater or less difference of electrical tension between the atmosphere and the surface of the ground. If then—in accordance with the views of Prof. Andrews as to the continuity of the liquid and gaseous states of matter, from which it follows that the change of other physical properties must also be continuous—we regard the particles of vapour suspended in the electric bodies in relation to the dielectric principal constituents of the atmosphere, they will be polarised by induction from the ground. This polarisation will give rise to an attraction between every particle and the neighbouring particles above and below it; and being stronger in the particles near the ground than in those more remote, the tendency of the particles to coalesce—which will increase, by their mutual induction, as two neighbours approach each other—will be greatest near the ground. Thus it may be, each particle gathering to itself its neighbours in succession till their united density exceeds that of the atmosphere generally, some rain drops are formed, and that in greatest abundance near the ground. If this be the true cause of any substantial part of the phenomena in question, then, as the variation in intensity of electrical polarisation of the particles will vary with the height most rapidly near the ground, so the variation in the rainfall near the ground should be more rapid than at a greater elevation, and such is indeed the fact. Also, if the idea be correct, it will probably serve to explain other phenomena which it was not specially conceived to meet; and so it does. For, first, it requires that the rainfall over even ground, where the electrical tension is relatively weak, should be less than over similarly situated forest land, where at the tops of the trees, ends of branches, and edges of leaves, the tension is high, and this is in accordance with observation. And, secondly, the tension being relatively high at the tops of the elevations of a mountainous district, the rainfall should be greater there than in the neighbouring plains; this, again, is borne out by observation. Further, at the commencement of a passing thunderstorm, a sudden heavy shower of rain will often fall for a few moments and then suddenly cease. May not this arise from the approach, by the agency of opposite wind currents, of detached masses of differently charged clouds, the process just described of formation of rain drops going on rapidly in each mass as the two come near each other, and stopping when, by a flash of lightning between them, the two masses are brought into the same electrical condition? An experimental test of this idea would be to repeat Dalton's measures of the pressure of vapour in the vacuum space of a mercurial barometer tube—filling that space with air and a little water, and compare the values found when the mercury was charged with electricity and when not so charged. If in the former case a less pressure was found, we might conclude that the particles of vapour are really susceptible of electric induction, and the amount of difference existing would enable us to estimate whether the attractions of the particles upon each other were strong enough to cause the formation of rain-drops hypothetically attributed to them above.

SECTION C.—GEOLOGY

On the Mountain Limestone of Flintshire and part of Denbighshire.—Mr. G. H. Morton. Minute details of the physical structure of the region, and lists of the fossils, showed that these beds have been erroneously referred to the Millstone Grit, and that they were really Mountain Limestone, the shales and sandstones being intercalated among the typical rocks. The white limestone was an ancient coral reef, with the organisms exquisitely preserved. Mr. Hughes protested against co-relating with the Yorkshire beds, while Mr. Bailey supported the opinions of the author.

On the formation of Swallow-holes, or Pits with vertical Sides, in Mountain Limestone.—Mr. L. C. Miall. The author distinguished between cavities formed by direct excavation and those produced by subsidence of part of the roof of a cavern. The curious pits near the Buttertubs Pass at the head of Swaledale, were regarded as typical of the first kind, and their appearance and mode of formation were described, especially the vertical fluted sides and the isolated fluted pillars, which were ascribed to the action of dropping water, aided by pebbles. A basin is first formed upon a ledge of rock, and as the excavation proceeds it produces a semi-cylindrical scar, with sharp ridges upon the face of the limestone wall, as if cut by a gauge. The presence of a thick surface-covering of alluvium or drift was necessary to absorb and retain the rainfall, and to distribute it slowly and regularly. The limestone of a bare plateau furnishes fissures in great variety, but they are not true swallow-holes. Regular and well-marked joints were also necessary to the production of fissures, as they permitted the ready escape of the waters of erosion. The texture of mountain limestone, and its power of receiving and retaining sharp impressions, gave the peculiar features to the swallow-holes excavated in it. Some swallow-holes were due to the subsidence of an undermined crust. These frequently lie in a line, sometimes in a ring round a hill-side. A particular description of some near Ripon was given, and the testimony of eye-witnesses as to their sudden appearance was quoted. Swallow-holes are often disguised by surface accumulations. Many conical hollows in drift are probably due to concealed cavities of subsidence.

On the Stratigraphical Distribution of the British Fossil Gasteropoda.—Mr. J. L. Lobley. This was the third of a series of reports by the author on British fossil mollusca. By the help of diagrams were shown the distribution of the species, and the range, increment, decrement, and maximum development of the genera, families, and orders of the *Gasteropoda*. The cainozoic deposits contain the greatest number of genera and sub-genera, though they are numerous also in both the mesozoic and palæozoic rocks. A large number of genera and sub-genera are characteristic of single formations, and these are especially numerous in the carboniferous limestone, the lower lias, the middle Eocene, and the older and newer Pliocene. Details of the range and of the distribution of species of each of the

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* A perfect transparency of the gas mass to all rays emitted by itself is here assumed, a supposition which is the nearer the truth the smaller the weights compared.