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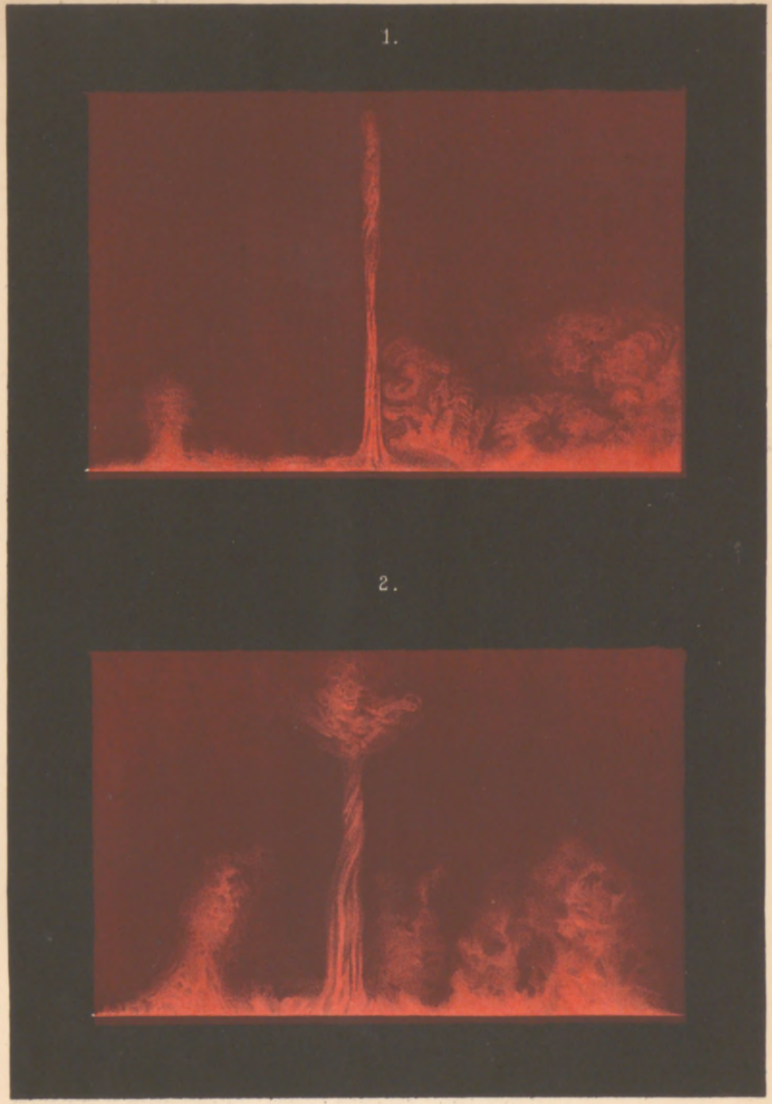

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FIGURE I.
Position 160°
Time, 10^h 22^m

FIGURE 2.
The same Protuberance
Time, 11^h 20^m

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F. ZÖLLNER; ON THE TEMPERATURE AND PHYSICAL CONSTITUTION OF THE SUN.

[Report of the Royal Saxonian Scientific Association. Mathematical and Physical Class. Session of the 2d of June, 1870.]

[From the Journal of the Franklin Institute.]

LEHIGH UNIVERSITY, *Sept.* 15, 1870.

To the Editors of the Journal of the Franklin Institute.

GENTLEMEN:—Quite recently I have received from my friend, Prof. Zöllner, an important memoir "On the Temperature and Physical Constitution of the Sun," a translation of which I forward you for publication in the *Journal of the Franklin Institute*, which has ever kept us so well informed of all that relates to solar physics.

Prof. Zöllner's memoir accompanied the following letter:

"LEIPZIG, *July* 30, 1870.

TO PROF. A. M. MAYER, PH. D.

"MY DEAR SIR:—I have waited until to-day to fulfill the duty of answering your agreeable letter and tendering my thanks for the reception of the reports of your investigations. I hope you will excuse my delay. It was my intention to reciprocate your favor by sending you the accompanying report, the completion of which required a longer time than I had originally supposed.

"At the present time, when Germany is arming for a struggle of life and death, and when the waves of national enthusiasm surge even into the quiet workshops of science, successful investigations are out of the question. I am, therefore, doubly glad that I have finished the present work before the beginning of the great catastrophe. It contains a sketch and the principal points of a longer, separate treatise upon the sun, which was to follow this report in a few months. Under the existing circumstances, however, I will probably want the necessary repose to finish it in so short a time.

"Receive the assurance of my especial esteem and favor again, with a few lines.

"Yours, sincerely, F. ZÖLLNER."

I.—AMONG the characteristic shapes of the protuberances,* which can now be observed at any time with a spectroscope having a widened slit, there is a considerable number which must convince

* The forms of the protuberances may be divided into two characteristic groups: *vaporous* or *cloudy* and *eruptive*. The preponderence of one or the other type seems to depend partially on local conditions of the solar surface and partially on

every unprejudiced observer that they are due to violent eruptions of incandescent hydrogen.

It is impossible, without passing beyond the well-known analogies necessary for the explanation of cosmical phenomena, to assign any other cause to these eruptions than the difference of pressure of the gases emanating from the interior and from the surface of the sun. To make such a difference of pressure possible it is necessary to admit the existence of a separating stratum between the inner and outer strata of hydrogen—the latter of which, as is well known, forms an important portion of the solar atmosphere.

The admission of this separating layer seems inevitable at the first sight of the protuberances, even to those observers who, like Respighi, do not deem it improbable that these eruptions are due to electrical causes.

But if we retain the more simple, and, therefore, more natural explanation by difference of pressure, we will be able to draw important conclusions in reference to the temperature and physical structure of the sun by following out the mechanical theory of heat and of gases.

From the premises of the mechanical theory for unliquifiable gases follow:

1. Marriotte's and Gay Lussac's Laws.

2. The constancy of the relation of specific heats under constant volume and constant pressure.

This constant quantity, determined for a certain gas by well-known methods, must be considered as invariable (like the atomic weight of a body), according to the mechanical theory of gases, and must not be classified with other empirical constants, such as the power of conducting heat, or the coefficient of expansion of solids and liquids. These constants are true only within the limits for which they have been ascertained by observation, and lose their significance if these limits are considerably exceded.

According to this assumption, I consider the eruptive protuber-

the time, so that at certain times one or the other type may preponderate. The fact that the cloud-like formations remind us so vividly of terrestrial clouds and vapors is easily explained, if we consider that the forms of our clouds are not due to the vesicles of water suspended in them, but to the manner in which heated air in motion expands.

The vesicles of vapor in terrestrial clouds only form the means through which the above-mentioned differences of masses of air become visible. The clouds of the protuberances are made visible by the incandescence of glowing hydrogen.

ances as a phenomenon, due to the flow of a gas from one space into another, while the pressure in both is constant, and neither communication nor absorption of heat is assumed.

Let A = the equivalent of heat for a unit of work;
v = the velocity of the flow of the gas in the plane of the opening;
g = the intensity of gravitation on the sun;
x = the relation of the specific heats of the gas under constant pressure and constant volume;
c = the specific heat of the gas under constant volume, in its relation to an equal weight of water;
t_i = the absolute temperature of the gas in the inner space from which it emanates;
t_a = the absolute temperature of the emanating gas in the plane of the opening through which it flows;
p_i = the pressure of the gas in the inner space;
p_a = the pressure in the plane of the opening.

According to the mechanical theory of heat these nine magnitudes bear to each other the following relations:*

$$A \frac{v^2}{2g} = x c (t_i - t_a), \quad . \quad . \quad . \quad . \quad [1.]$$

$$\frac{t_i}{t_a} = \left(\frac{p_i}{p_a}\right)^{\frac{x-1}{x}}, \quad . \quad . \quad . \quad . \quad . \quad [2.]$$

Furthermore, let a_1 = be the mean height of the barometer in mêtres of mercury;
ρ = the density of the gas at the temperature of melting ice under the pressure of the column of mercury a, and on the surface of the earth;
σ = the density of the gas in the inner space under the pressure p_i and at the absolute temperature t_i;
α the coefficient of expression of the gas for 1° C.

According to Marriotte's and Gay Lussac's Law, we have—

$$\sigma = \frac{\rho}{a_1 \alpha} \cdot \frac{p_i}{t_i}, \quad . \quad . \quad . \quad . \quad . \quad . \quad [3.]$$

The pressure p_a in the plane of emanation may be considered

* Zeuner, Elements of the Mechanical Theory of Heat. Second edition: 1866, p. 165.

equal to the pressure of the solar atmosphere at the level of the above-mentioned separating stratum (*i. e.* at the base of the atmosphere). Then let

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 of the atmosphere assumed as constant—the law of temperature not being known;

g = the gravity of the sun at the base of the atmosphere;

r = the radius of the separating stratum;

ρ_1 = the specific gravity of mercury at the temperature of melting ice;

g_1 = the intensity of gravity on the surface of the earth;

a_1 = the mean height of the barometer;

ρ = the density of the gas of the atmosphere at the temperature of melting ice and under the influence of the magnitudes g_1 and a_1.

Then we have by a well-known process:

$$\text{log. nat.} \left(\frac{p_a}{p_h}\right) = \frac{\rho\, g\, r\, h}{\rho_1\, g_1\, a_1\, \alpha t\, (r + h)}, \quad . \quad . \quad . \quad [4.]$$

In order to combine this equation with the three preceding ones we must assume:

1. That the principal component of the solar atmosphere, which produces the pressure p_a, consists of the same gas which emanates from the interior of the sun to form the eruptive protuberances.

2. That the absolute temperature t, of the atmosphere is equal to the absolute temperature t_a, at the plane of the opening through which the gas passes.

The first of these assumptions I consider amply justified, because the discovery of the so-called chromosphere furnishes the proof that the whole surface of the sun is actually enveloped by a considerable atmosphere of hydrogen.

I am led to the second assumption by the fact that there is scarcely any difference in the brilliancy of the basis of all eruptive protuberances from that of the chromosphere. If we consider, moreover, that the constant mean temperature t, in formula [4], which has been substituted for the temperatures decreasing for the height h (because the law of the decrease is not known), must correspond to that of a stratum near the base,* then this temperature approaches that of the outer surface of the separating stratum.

According to the first supposition, ρ in formula [4] becomes identical with that in [3], and according to the second

$$t = t_a.$$

II.—After explaining the theoretical principles necessary to the consideration of the solar phenomena, we will now simplify the above equations.

If H is the height to which a body will ascend perpendicularly with an initial velocity v on the surface of the sun, we have, considering the decrease of gravity:

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

or,

$$\frac{v^2}{2\, g} = \frac{r\, \text{H}}{r + \text{H}}.$$

Substituting this value of $\frac{v^2}{2\, g}$, in formula [1], we have

$$t_1 = \frac{r\, \text{H A}}{x\, c\, (r + \text{H})} + t_a\, ;$$

or if $\frac{r\, \text{H A}}{x\, c\, (r + \text{A})} = a$, and according to our supposition $t_a = t$, we get for formula [1] $t_1 = a + t$. . . . . [I.]

Then let $\frac{x - 1}{x} = \frac{1}{q}$, $\frac{\rho}{a_1\, a} = b$ and $\frac{g}{g_1\, \rho_1} = m$. Then will formulas [2], [3] and [4] become

$$\frac{t_1}{t} = \left(\frac{p_1}{p_A}\right)^{\frac{1}{q}} \quad . \quad . \quad . \quad . \quad [\text{II.}]$$

$$\sigma = b\,\frac{p_1}{t_1}, \quad . \quad . \quad . \quad . \quad . \quad [\text{III.}]$$

$$p_a = p_h\, e^{\,b\, m\, \frac{r\, h}{(r + h)\, t}}, \quad . \quad . \quad [\text{IV.}]$$

* In reference to the increasing density of the air towards the base, the temperature in formula [4] (independently of the special law for decrease of temperature), must correspond to the temperature of a layer which is *lower* than $\frac{h}{2}$. This difference, which is generally very considerable, as is shown by a simple calculation, seems to be generally neglected in determining heights by the barometer (in which the mean temperature of the two stations is used); and this circumstance seems to explain periodical phenomena, observed lately, in a very simple manner.

From these we obtain by elimination:

$$\sigma = \frac{b\,p_h}{a+t}\left(\frac{a+t}{t}\right)^q e^{\frac{b\,m\,r\,h}{(r+h)\,t}}, \quad . \quad . \quad . \quad . \qquad [V.]$$

This equation, therefore, expresses the density σ of the compressed gas only as a function of the three magnitudes p_a, h and t. If, therefore, under the above suppositions, we can determine three of the four magnitudes by observation or keep them within limits, we can obtain the fourth. Now, by means of spectroscopic and other observations σ, p_h and h can be actually determined within certain limits, so that we may also limit t, the temperature of the outer hydrogen atmosphere near the glowing liquid separating stratum. Substituting this value in [I.] (H being known), we obtain a value for the inner temperature t_i, and [III.] and [IV.] also yield values for p_i and p_a.

III.—In the discussion of numerical values, I will begin with formula [I].

The lowest value assignable to t is, of course, 0. Then t_i becomes a minimum:

$$t_i = a - \frac{r\,H\,A}{x\,c\,(r+H)}, \quad . \quad . \quad . \quad . \quad . \qquad [5]$$

On account of the fact that the density of the atmosphere almost becomes zero, even at a moderate distance from the surface and the resulting slight resistance, H may for simplicity be made equal to the mean height of the protuberances. The conditions necessary for this will be discussed further on.

Not unfrequently the protuberances attain the height of 3 minutes. In order to keep within the bounds of a mean value, I will take H at 1·5 minutes. Assuming the metre and degree centigrade as units, the equivalent of heat $A = \frac{1}{424}$. The product, $x\,c$, according to the latest researches of Regnault (*Pogg. Ann.* 89 vol.) equals 3·409 for hydrogen. According to Dulong (*Ann. de Chem. et de Phys.* t. 41) the value of x for hydrogen equals 1·411.

The numerical value of r requires a somewhat longer discussion. This is the radius of the separating stratum, from which the protuberances emanate. Here the question arises whether this value coincides with that of the solar radius, *i. e.*, whether this stratum coincides with the boundary of the luminous solar disc used for our measurements.

The latest investigations of Frankland and Lockyer, St. Claire-

Deville and Wüllner have proved that the broken spectrum of hydrogen and other gases may be changed to a continuous brilliant one by increasing the pressure. When this is done the bright lines of the broken spectum undergo very characteristic changes, which consist principally, as in the line $H\beta$, in a widening and increasing blurring of outline.

From these changes we may, within certain limits, draw conclusions concerning the amount of pressure, as Frankland and Lockyer have indeed done. They believe "that at the lower surface of the chromosphere itself the pressure is very far below the pressure of the earth's surface."

The investigations of Wüllner, I believe, even justify the assumption that the pressure at the base of the chromosphere or at the extreme edge of the luminous solar disc must be between 50 mm. and 500 mm. of a mercury barometer on the earth's surface.

For this reason the presence of dark lines in the solar spectrum on a continuous ground does not necessitate the assumption that this continuous spectrum is caused by the incandescence of a solid or liquid; for we may with equal right assume that it is due to the incandescence of a more highly compressed gas.

Wüllner has even proved this experimentally for the sodium-line, and he makes the following observations:

"At a pressure of 1,230 mm. the maximum at $H\alpha$ falls back still further; the whole spectrum becomes dazzling, and the sodium-lines appear as beautiful dark lines;* a proof that the light of hydrogen is intense enough to produce a Fraunhofer's line in an atmosphere of sodium, and that the light of an incandescent solid is not necessary."

It follows from this that the radius of the visible solar disc is not necessarily identical with that of the assumed separating stratum, but that the latter probably lies below that stratum, where the spectrum of the hydrogen atmosphere becomes continuous by increased pressure. This view is supported by the appearance of solar spots.

Nearly all observers, however different their theoretical opinions about the nature of the solar spots, agree in that the nucleus of

* In consequence of the high temperature of the tube, sodium from the glass becomes vaporized. At a pressure of 1,000 mm. the sodium-lines are still bright, (l. c. p. 345.)

these spots must be deeper than their surroundings.* This depth is taken at about 8″, partially from direct (De la Rue, Steward, Lœwy) and partially from indirect observations (Faye).†

If the nucleus of the solar spots is considered as a scoriaceous product of local cooling on a liquid surface, and the penumbræ as clouds of condensation, which surround at a certain height the coasts of these islands of slag,‡ then the simplest supposition is that the liquid surface (necessary to support this theory) is identical with the surface of the separating stratum in question, from which the protuberances burst forth. If R represents the observed solar radius in seconds, then the radius r of this surface would be approximately,

$$r = \text{R} - 8''.$$

Or R at 16′ at the mean distance of the sun, $r = 15' \, 52''$.

If the mean parallax of the sun is taken at 8″ ·915, according to Hansen, then

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

$$\text{therefore, } 8'' = 5{,}722{,}500 \text{ "}$$

In order to determine numerically the absolute minimum temperature in the space, from which an eruption of 1·5 minutes height takes place, we must substitute the following values in fomula [5]:

$$r = 680{,}930{,}000;$$
$$\text{H} = 64{,}370{,}000;$$
$$\text{A} = \frac{1}{424};$$
$$xc = 3{\cdot}409.$$

Then we will find that

$$t_1 = 40690°.$$

If we substitute for H double the above value, which would cor-

* Spörer, however, says: We consider the spots as cloud-formations above the luminous surface of the sun. The penumbra is nothing more than an aggregation of small spots, the spaces between which allow the luminous surface to shine through, *above* which the spot is situated.—*Pogg. Ann.* vol. 128, (1866.)

† Faye, by computations based on the observations of Carrington, finds that this depth is 0·005 — 0·009 of the solar radius.—*Comptes. Rendus*, LXI., 1082—1090.

‡ This theory has been indicated by me in my photometric observations, p. 245, five years ago, and further developed last year in the quarterly report of the *Astrom. Soc.*, year IV., No. 3, p. 172. I reserve a still further development and explanation by means of the spectroscopic observations on solar spots, for a paper soon to be published.

respond to a protuberance of 3 minutes height, then the minimum value of

$$t_1 = 74910^\circ.$$

Here, however, the question arises, whether we have a right to substitute the extremes of the observed heights of protuberances in our formulæ for H, which stands for the distance to which a body, thrown up vertically from the sun, would rise without resistance. If we actually have to do with burning masses of hydrogen, as observation proves beyond a doubt, their rising may be due equally well to Archimedes' principle, like that of heated gases in a chimney, by becoming specifically lighter than the surrounding atmosphere. These two causes would, however, differ materially in the *time* necessary for the gaseous masses to reach a certain height. Without entering into a special discussion of this point, it is clear that the time needed by a protuberance to rise to a given height, by Archimedes' principle, must in all cases be greater than by a force throwing it vertically up to the same height without resistance and with a certain initial velocity.

Therefore an observation made as accurately as possible on the time required by a protuberance to reach a certain height will decide whether this height is due to the former cause, and in that case only can the light be used as an integrating component of the above formulæ.

According to the supposition, the opening through which the protuberances pass, lies in the liquid incandescent separating stratum at a depth $h = 8''$ under the visible limit of the solar disk. H, in the above formula, meant the height of a protuberance from the plane of the opening.

Let τ = the time required by the protuberance to reach the height, H, *from the opening.*

τ_1 = the time required by the protuberance to reach H from h, the outer limit of the photosphere.

v = the velocity at the opening.

v_1 = the velocity at h.

Assuming the former cause, and neglecting the decrease of gravity (g), we have:

$$\tau = \sqrt{\frac{2\,\mathrm{H}}{g}}, \quad \tau_1 = \sqrt{\frac{2\,(\mathrm{H} - h)}{g}}.$$

$$v = \sqrt{2\,g\,\mathrm{H}}, \quad v_1 = \sqrt{2\,g\,(\mathrm{H} - h.)}$$

Assigning the following values:

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

we have

$$\tau = 11 \text{ min. } 25 \text{ sec.};\ \tau_1 = 10 \text{ min. } 54 \text{ sec.}$$
$$v = 187{,}900 \text{ m., or } 25{\cdot}32 \text{ geogr. miles.}$$
$$v_1 = 179{,}400 \text{ m.,} = 24{\cdot}17 \text{ `` ``}$$

If, therefore, we observe such a velocity in a protuberance, we are justified in substituting the corresponding height in our formulæ. I have observed such a velocity frequently, and take the liberty of placing before you the drawing of a protuberance whose velocity corresponds very well with the above. (Figs. 1 and 2, Plate I.)

Lockyer's* beautiful observation of the change of the refrangibility of light led him directly to exactly similar magnitudes. He found the maximum velocities of streams of gas moving vertically or horizontally in the chromosphere to be 40 and 120 English miles a second. The above values, reduced to English miles, become

$$v = 123{\cdot}1, \text{ and } v_1 = 117{\cdot}7,$$

and therefore correspond to those of Lockyer.

According to the mechanical theory of heat, such velocities of hydrogen necessitate differences of temperature amounting to 40690° C. We may, therefore, ascertain the temperature itself, if we can assign certain limits to the temperature, t, of the outer atmosphere of hydrogen. It has already explained why this temperature has been assumed as approximating that of the openings through which protuberances pass.

4. A limit for t may be found from formula V.

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

In this the density σ of the confined masses of gas is expressed as a function of p_{h}, h and t. I shall now show that σ cannot exceed a certain value, and that, therefore, t is also limited to a certain value, p_{h} and h having already been determined.

It has been shown before that the explanation of eruptive protuberances necessitates the existence of a separating stratum between the space *from* which they emanate and the space *into* which they pass. Nothing else would make the differences of pressure possible.

* *Proceed. R. S.*, No. 115 (1869), and Comp. Rend., T. 69, p. 123.

In reference to its physical condition, we must furthermore assume that it cannot be gaseous, and must, therefore, be either solid or liquid. The former being improbable, on account of the high temperature, we must conclude that the separating stratum consists of an incandescent liquid.

In reference to the inner masses of hydrogen bounded by that stratum, two suppositions are possible, viz.:*

1. The whole interior of the sun is filled with incandescent hydrogen gas, which would make the sun an immense bubble of hydrogen surrounded by a liquid glowing envelope.

2. The masses of hydrogen, bursting out into protuberances, are local collections in bubble-like caverns, which form in the superficial layers of a liquid glowing mass, and burst through when the presence of the confined gas increases.

Under the first supposition, stable equilibrium could only exist if the specific gravity of the outer layer is less than that of the gas below it. Since the density of a globe of gas whose particles are subject to Newton's and Mariotte's laws increases towards its centre, the specific gravity of the outer bounding layer must necessarily be less than the mean specific gravity of the sun. But if we take the mean specific gravity of the sun as the maximum of liquid outer layer, we would be obliged to assume that all deeper layers, including the gaseous one immediately below, have the same specific gravity.

Then the interior of the sun could not consist of a gas, but of an incompressible fluid. All these properties are clearly a necessary consequence of the supposition that the specific gravity σ of the compressed gases forming the protuberances reaches as its maximum the mean specific gravity of the sun.

In that case, we must suppose, secondly, that the sun consists of an incompressible liquid, near whose surface there are collections of glowing masses of hydrogen, which break through bubble-like caverns as eruptive protuberances under certain differences of pressure.

However small these caverns may be in special cases, the specific gravity of the enclosed gases cannot be greater than that of the

* The phenomenon of the formation of bubbles cannot be adduced as an argument against this, because the conditions are entirely different, since the molecular attraction of the envelope keeps the confined gases in equilibrium, and the gravitation of the particles disappears. In the above case, the very opposite takes place. The molecular attraction is insignificant, compared with the gravity of the mass.

surrounding liquid, because, otherwise the compressed gases would sink towards the interior of the sun.

The specific gravity of the sun, according to the latest determinations, is 1·46. If this is substituted for σ, 40690 for a in (Form. V.) and 8″ in metres for h, then, if

$p_h = 0·500$ m. $t = 29500°$

and if $p_h = 0·050$ m. $t = 26000°$

mean value, $t = 27700°$.

If equation (5) is differentiated with respect to t, then $\frac{d\sigma}{dt}$ becomes negative, *i. e.*, σ decreases for increasing values of t. Hence it follows that the above values for t are also minima.

From this mean value of t, for the temperature of the solar atmosphere, the value of p_h is found to be 0·180 m. These values are the basis of the following calculations:—

The temperature found is about 8 times higher than that resulting from the combustion of an explosive mixture, (Bunsen "On the Temperature of Carbonic Oxide and Hydrogen Flames," Pog. An., CXXXI., p. 172,) and iron must exist, as a permanent gas, in the solar atmosphere.

With the value $t = 27700°$, the inner temperature in formula (I) becomes $t_i = 68400°$.

If the values of t_i and t are substituted in formula (II) we obtain

$$\frac{p_i}{p_a} = 22·1,$$

i. e., the pressure in the interior of the space from which the protuberances emanate is 22·1 times greater than the pressure at the surface of the liquid separating layer. If the value of t is substituted in formula (IV) and h is taken at 6″ as before, $\frac{p_a}{p_h} = 766{,}000$, the relation of the pressure on the liquid surface of the sun to that at the height, h, where the hydrogen spectrum begins to become continuous on account of the pressure.

If, for p_h we substitute the above value of 0 180 metres of mercury, get

$p_a =$ 184,000 atmospheres.

and $p_i = 4{,}070{,}000$ "

If we calculate the depth at which the maximum pressure of p_i would be reached in the liquid solar mass of 1·46 specific gravity in consequence of hydrostatic pressure alone, we will find that it will take place at a depth of 139 geographical miles below the surface, *i. e.*, in a depth of 1·46 seconds of arc, or $\frac{1}{858}$ of the sun's radius.

Even if we neglect to consider the liquid state, and calculate that depth where the atmospheric pressure becomes equal to the internal pressure, p_i, assuming a much greater atmospheric envelope of hydrogen, we will find, even with a temperature of 68,400°, that it will be only 27″ under the visible edge of the solar disk, or about $\frac{1}{36}$ of the apparent solar radius.

This shows how rapidly the pressure must increase towards the interior of the sun, and justifies the assumption, that even at such enormous temperatures permanent gases, as, for instance, hydrogen, can only exist in a liquid glowing state in the interior of the sun.

5. An interesting result is obtained if we calculate the pressure in an atmosphere of nitrogen and oxygen, equal in weight and temperature to the above hydrogen atmosphere, at the height where the hydrogen spectrum becomes continuous. If we suppose the pressure of the three atmospheres of H, O and N, to be equal, (p_a = 184,000 atmospheres, which would correspond to the above value of p_h,) at a depth of 8″ under the visible edge of the solar disk, *i. e.*, at the level of the supposed separating stratum, when at the calculated temperature of 27,000°, the pressure of each of the three atmospheres on the surface of the *visible* solar disk would be as follows:

Hydrogen, $p_h = 180$ millimetres.

Nitrogen, $p_h = 323 \frac{1}{10^{78}}$ "

Oxygen, $p_h = 124 \frac{1}{10^{88}}$ "

Hence it follows, that under the above suppositions, the quantity of the last two gases must be considered as extremely small, compared with that of hydrogen, in that stratum where the spectrum of hydrogen becomes continuous. This would even be so if we should assume the weight of the two atmospheres as many million times greater, although, according to their specific gravities $\frac{1}{14}$ of the quantity of nitrogen and $\frac{1}{16}$ of oxygen would suffice to make the density of these gases *at the base* equal to that of hydrogen. The mean specific gravity of the sun would have to be taken as the maximum of density at the base of these atmospheres, and we can easily calculate from formula (III) and the known specific weights of oxygen and nitrogen what the weight of these atmospheres would have to be in order to reach that maximum.

The result shows that the weight of the atmosphere of oxygen would only have to be 0·56, and of nitrogen 0·64 that of the hydrogen atmosphere.

If we suppose the *simultaneous* presence of all three gases on the surface of the sun, and neglect for the present the influence of the motion of the atmosphere, the rays emanating from these strata which give a continuous hydrogen spectrum, would pass through so slight a quantity of glowing oxygen and nitrogen that the absorption would be insignificant, and the presence of O and N would not be indicated by dark lines in the spectrum, as is actually the case.

Although the motion of the gases would tend to diminish the above differences, the existence of the chromosphere proves the slightness of this influence in consequence of the intensity of gravitation and the great height of the stratum in question. (Compare Form. 4.)

In order, however, to explain the absence of lines of two such universally diffused bodies as N and O in the solar spectrum, we must also consider the slight emissive power of permanent gases as compared to that of vaporized solids.

If we consider the emissive power of different gases at the same temperature, and for rays of the same refrangibility, with reference to very small quantities of these gases,* the above experiment of Wüllner, in which the slight quantity of sodium vaporized from the glass of a Geissler's tube emitted more light than hydrogen under 1,000 mm. pressure, furnishes the most beautiful proof of the exceedingly great difference in the emission and (according to Kirchhoff's law of the) absorbing power of different gases at the same temperature. This will answer the objection to the above explanation of the absence of N and O lines, that the solar spectrum contains the lines of bodies, the density of whose vapors is much greater, in consequence of their relation to the atomic weights, than that of oxygen and nitrogen.

From these considerations we obtain either directly or indirectly, by deductions, the explanation of which I reserve for another place, the following conclusions:

* We assume here the perfect transparency of the gas for the rays emitted by it; an assumption which comes nearer the truth the smaller the compared quantities of gas are.

1. The absence of lines in the spectrum of a self-luminous star does not prove the absence of the corresponding bodies.

2. The stratum, in which the reversion of the spectrum takes place, is different for every body, and lies the nearer to the centre of a star the greater the density of the vapor and the less the emissive power of the body is.

3. In different stars this stratum, other things being equal, lies the nearer the centre the greater the intensity of gravitation.

4. The distances of the strata of reversion for different bodies from the centre of the star and from each other increase with the temperature.

5. The spectra of different stars contain the more lines, under similar circumstances, the less their temperature and the greater their mass is.

6. The great difference of intensity in the dark lines of the spectrum of the sun and other fixed stars depends not only on the differences of absorption but also on the different depths at which the reversion of the spectra takes place.

In conclusion, I may be permitted to make a few remarks concerning the application of experiments with rarified gases to the heavenly bodies. Lecoq de Boisbaudran (*Compt. Rend.*, t. 70, p. 1091, 10 Mai, 1870,) has recently stated (with reference to Wüllner's investigations of rariability of spectra by pressure and increase of temperature,) that we should be cautious in applying the results so obtained to the consideration of the solar atmosphere, because the changes of the spectra were due far more to temperature than to pressure. Even supposing that this would be verified by experiment, it would only slightly influence the results in the present dissertation. For, the nature of formula [5], by which the temperature of the atmosphere was obtained, is such that the pressure p_h, at which the spectrum of hydrogen becomes continuous, may be very considerably changed without greatly changing the temperature. We have seen that pressures standing to each other as 1 : 10 would produce values of temperature standing as 1 : 1·15.

Nevertheless, the separation of the influences exercised by pressure and temperature on the spectra of luminous gases must be considered as a problem, whose solution is of the highest importance.

Perhaps we shall be able by application of the well-known law of the heating power of galvanic currents and the law of Gay Lussac so to regulate the pressure of the gas by changing the level of mercury that the increase of pressure produced by the temperature during a stronger discharge is compensated by a diminution of pressure produced previous to the discharge. In this way the pressure would be kept constant, and we would be able to investigate the effect of changes of temperature on the spectrum without knowing the temperature itself. In this we would neglect the loss of heat caused by conduction and radiation during the short space of the discharge, and make the heat developed in the current approximately proportional to the temperature of the glowing gas. If the mass of the gas is known we can calculate the maximum absolute temperature of the glowing gas from the time and temperature of the discharge.