II.—*On the Constitution of Flame.* By WILLIAM SWAN. Esq.

(Read 17th January 1859.)

If we examine the flame arising from the combustion of any of the hydro-carbons, such as that of coal-gas, or of a common candle, it will be found to consist of several portions easily distinguishable by the eye, and in which the matter composing the flame exists in very different conditions. There is, *first*, a central non-luminous region, in which the gases are not yet ignited; *secondly*, a blue conoidal envelope, extending from the wick or burner, and gradually thinning out towards the top of the flame; *thirdly*, a more or less luminous conoid, thin towards the bottom of the flame, where it is enveloped by the blue conoid, but thicker towards the top. And *fourthly*, a faintly luminous outer envelope, completely surrounding the other portions of the flame, and greatly developed towards the top.

In the blue part of the flame, where the supply of oxygen is abundant, the carbon seems to undergo combustion in a gaseous state along with the hydrogen. In the interior luminous region, where there is less free oxygen, carbon is disengaged in a solid form, and the brilliant light which is generated arises from the incandescence of its particles. The exterior envelope is supposed to consist of matter which has undergone combustion, but which is still at so high a temperature, as to be incandescent.

When a flame is urged by a blow-pipe, a large supply of oxygen is forced into it. The greater portion of the carbon, which otherwise would have appeared in a solid form, before undergoing combustion, is consumed in a gaseous state. The blue part of the flame thus becomes greatly developed, and appears as a sharp well defined cone; while the faintly luminous envelope surrounding it also assumes a regular conical form. The inner blue and outer faintly luminous cones are well known to chemists as possessing very diverse properties. In the outer cone, from the presence of an excess of oxygen, bodies become rapidly oxidated; while in the inner cone, from the redundancy of uncombined inflammable matter, a powerful deoxidizing energy is exerted. Such are the principal facts hitherto recognised regarding the constitution of flame.

Two years ago, when I was engaged in a series of experiments on the prismatic spectra of the flames of the hydro-carbons, my attention became directed to Professor DRAPER'S very ingenious paper, "On the Production of Light by Chemical Action," in the 32d vol. of the *London Philosophical Magazine*. In that paper, the author advances an entirely new view regarding the nature of

flame, founded on the principle, that “There is a connexion between the refrangibility of the light which a burning body yields, and the intensity of the chemical action going on; and that the refrangibility always increases as the chemical action increases.”* On this principle, Professor DRAPER reasons as follows:—“All common flames, as is well known, consist of a thin shell of ignited matter, the interior being dark, the combustion taking effect on those points only which are in contact with the air. From the circumstances under which the air is usually supplied, this ignited shell cannot be a mere mathematical superficies, but must have a sensible thickness. If we imagine it to consist of a series of strata, it is obvious that the phenomena of combustion are different for each. The outer stratum is in absolute contact with the air, and there the combustion is most perfect; but by reason of the rapid diffusion of gases into one another, currents, and other such causes, the atmospheric air must necessarily pervade the burning shell to a considerable depth; and in the successive strata, as we advance inwards, the activity of the burning must decline. On the exterior stratum oxygen is in excess, at the interior the combustible vapour, and between these limits there must be an admixture of the two, which differs at different depths.” Admitting the principle already enunciated, Professor DRAPER adds,—“It follows, that each point of the superficies of every flame, no matter what the combustible may be, must yield all the colours of the spectrum, the violet coming from the outer strata, the yellow from the intermediate, and the red from those within. If we could isolate an elementary horizontal section of a flame, it should exhibit the appearance of a rainbow ring.”†

The results I had obtained in my experiments, led me to doubt the correctness of these views; for I found, that while the envelope of a hydro-carbon flame formed an absolutely *continuous* spectrum, extending from about the line C nearly to the line H of FRAUNHOFER, the bright inner cone formed a totally independent spectrum of superior brilliancy, also quite *continuous*, and of still greater extent; and the blue cone had a remarkable interrupted spectrum, peculiarly its own, whose extreme visible portions lay, respectively, between the lines D and E, and close to the line G of FRAUNHOFER. While my experiments thus amply confirmed what was already known regarding the very diverse character of the different portions of a hydro-carbon flame, they at least did not corroborate the idea of the refrangibility of its light, varying from its outer to its inner regions. Thus, the envelope, the blue conoid, and the bright conoid, which successively enclose each other, all produce spectra, having rays corresponding with the lines B and G of FRAUNHOFER; lines which differ greatly in refrangibility. It was, moreover, a matter of perfect indifference, so far as I could ascertain, from what precise point the light was derived. Whether the light were taken from near its outer

* Philosophical Magazine, vol. xxxii., p. 103.

† Ibid., vol. xxxii., p. 104–105.

or inner surface, each conoid always produced its own peculiar spectrum, or rays of the same refrangibility. In describing my experiments, however, I purposely made no reference to Professor DRAPER's peculiar views, for I had not then had leisure to examine them with sufficient care. The object of the present paper is to state the result of a careful repetition of the principal experiments by which Professor DRAPER conceives he has demonstrated the existence, in flame, of concentric layers producing light of varying degrees of refrangibility.

Professor DRAPER's method of analysing the light of a flame, which is exceedingly ingenious, is thus explained by him. "The instrumental arrangement I have employed is as follows:—The rays of the flame, of which the examination is to be made, pass through a horizontal slit one-thirtieth of an inch wide and one inch long in a metallic screen, and are received at a distance of six or eight feet on a flint-glass prism, the axis of which is parallel to the slit. After passing the prism, they enter a small telescope, which has a divided micrometer, and also parallel wires in its eye-piece. Through this telescope the resulting spectrum is viewed."* The reason why the slit is placed horizontally, and the light refracted in a vertical plane, he states to be as follows:—"In this arrangement the slit should be horizontal, and not vertical. So far from its being immaterial which of the two positions is selected, very great advantages arise from the former. If the slit be vertical, the prism, it is true, will separate the constituent colours from one another; but it fails to show their relative position. If it be horizontal, the relative positions of the different colours can be demonstrated; and it can be proved that a horizontal section of a flame is in reality, as has been already remarked, a coloured ring, the red being the innermost colour, and the violet outside; for if this is the order in which the colours occur, the red ring must necessarily have a less diameter than the green, and the green than the violet; and when the prism, set in a horizontal position, separates those colours from each other, the sides of the resulting spectrum ought not to be parallel, but inclined to one another, the breadth being least in the red, and increasing as we pass to the violet end." "This being understood, I may illustrate the facts now to be brought forward by an example of the prismatic analysis of a horizontal element of the flame of a spirit-lamp, it being understood that the prism is at its angle of minimum deviation, and the spectrum seen through the telescope. All the prismatic colours, in their proper order, are visible, the sides of the spectrum not being parallel, the inclination being quite rapid towards the red extremity, the rays of which come from the interior of the flame where the diameter is less. Mere inspection is sufficient to show the rapid approach of the red sides to each other; and I satisfied myself that even in the more refrangible regions there is the same want of parallelism, by rotating the telescope on its vertical axis, so that the vertical wires in its eye-piece might coin-

* Ibid., pp. 101–2.

cide with first one and then the other side of the spectrum." "But further, the yellow space of such a spirit-flame spectrum is crossed by a bright fixed line—Sir David Brewster's monochromatic ray. It is a beautiful example of the principles just pointed out in this method of horizontal analysis, being of much greater width than the rest of the spectrum, and recalling to the imagination the appearance of Saturn's ring when nearly closed, and seen through a telescope of moderate power. This ray, from its superior breadth, must necessarily come from that pale, tawny light which invests the bright part of the flame."* On this statement I will meantime only remark, that while, according to Professor DRAPER, the yellow space corresponding to the line D of FRAUNHOFER, has a much greater width than the rest of the spectrum, and while the inclination of the sides towards the red end of the spectrum is described as being "quite rapid," mere inspection sufficing to observe it, no such marked variation in breadth was observed in the more refracted portions of the spectrum. Professor DRAPER says, he "satisfied" himself that even in the more refrangible regions there is the same want of parallelism by rotating the telescope on its vertical axis, so that the vertical wires in its eye-piece might coincide with first one and then the other side of the spectrum." From this it is obvious that the supposed want of parallelism in the more refracted portion of the spectrum was so small as to be insensible to the unassisted eye, and required instrumental means for its detection. We are told that the breadth of the spectrum was ascertained by rotating the telescope on its *vertical* axis, so as to cause the wires in the eye-piece to coincide, alternately, with first one and then the other side of the spectrum; but we are nowhere informed in what manner the *amount* of the rotation was ascertained. It seems, however, to be highly probable, that since it took place round a *vertical* axis, the readings in the two positions of the telescope would give *the difference of azimuths* of the two sides of the spectrum. It is to be regretted that Professor DRAPER has not described his method of observation more explicitly; for I shall show in the sequel that the validity of his results depends entirely on whether the observations were, or were not, observations of azimuth.

I will now describe my own experiments. The flame to be observed was placed behind a horizontal metallic slit, 0.05 inch in width, and of sufficient length to allow the entire breadth of the flame to be seen. To prevent the disturbing effects of currents of air, the flame was surrounded by a four-sided sheet-iron chimney, having on the side next the slit an aperture covered by a piece of fine sextant glass, through which the light passed to the slit without undergoing any irregular refraction capable of affecting sensibly the results. The prism used was kindly lent me by Professor FORBES. It is a fine flint-glass prism, the workmanship of Secretan of Paris. The instrument employed for observing the spectrum was an excellent theodolite, constructed expressly for

* Ibid., pp. 106-7.

observations of prismatic spectra, by the late Mr JOHN ADIE. The telescope of this instrument is attached to an arm turning on the centre of a divided circle, so that the axis of the telescope is always in the plane of the circle. The stand which carries the prism also turns, independently, on the centre of the circle; so that although the telescope be moved through any angle to observe the rays refracted by the prism, the prism itself suffers no displacement. The prism-stand has screws by which the faces of the prism are made perpendicular to the plane of the circle. The circle was mounted on a temporary, but firm stand, so that its plane was vertical; and the distance of the prism from the flame was $15\frac{1}{2}$ feet nearly. During the observations, the prism suffered no displacement, except the very small one occasioned by turning it round its own axis, to bring it to its positions of minimum deviation for the different rays of the spectrum. The rotation necessary to effect this could not exceed, from the ascertained dispersive power of the prism, an angle of 2° ; so that the length of the path of rays proceeding from the flame through the prism to the eye was nearly constant; and hence the apparent distance of the flame, and its angular breadth, was sensibly the same in all positions of the telescope and prism. The telescope has a good object-glass of 1.6 inch aperture; and, with the eye-piece used in the observations, magnified twenty-one times. It is furnished with a micrometer, having a fixed wire in the centre of the field, and a moveable cross of wires.

The observations were made by first carefully adjusting the telescope to focus, and the prism to its position of minimum deviation. By means of a screw connected with the stand, the circle carrying the prism and telescope was moved round a vertical axis until the fixed micrometer wire coincided with one side of the spectrum. The moveable cross was then, by means of the micrometer screw, made to coincide with the other side of the spectrum; and the turns and parts of a turn of the screw read off. From the previously ascertained deviations by the prism for the principal lines of FRAUNHOFER, and the theodolite reading when the slit was viewed directly, it was easy to place the telescope so as to observe rays of any given refrangibility. Those chiefly observed corresponded with the lines B, *b* and G of FRAUNHOFER. It did not seem expedient to observe the extreme rays of the spectrum, as the faint illumination of these rays rendered their observation both difficult and unsatisfactory. The flames first examined were those of coal-gas, burned from a common jet with a single aperture. The spectrum observed was that of the luminous incandescent carbon conoid of the flame. The gas was supplied directly from the street pipes; but it was passed through one of MILNE'S regulators, in order to guard against the effects of varying pressure in altering the size of the flame. The flame, although subject to periodical fits of elongation, and slight lateral displacement, speedily returned to a nearly constant condition, and the observations were upon the whole satisfactory. They are exhibited in the following tables:—

OBSERVATIONS OF THE BREADTH OF THE SPECTRUM OF A COAL-GAS FLAME.

Line of Spectrum Observed.	First Set of Observations.	Second Set of Observations.	Third Set of Observations.
B	157	125	103
b	152	124	105
G	153	123	102

The numbers in the table are, in the first set of observations, the means of seven micrometer readings, and in the second and third sets, the means of twenty-four and eight readings respectively.

It will be seen that so far from the spectrum increasing in breadth towards its most refracted extremity, the measured breadths at the line G in the blue rays, are actually in every case less than those at the line B in the red rays of the spectrum.*

Having found the flame of gas, notwithstanding every precaution, to be subject to anomalous fluctuations, and being desirous, moreover, to repeat Professor DRAPER's experiments as faithfully as possible, I next observed the flame of a spirit-lamp fed by alcohol. It will be remembered that the spectrum of the flame of alcohol is that which he describes to illustrate his views. I did not anticipate, however, that such a flame would be convenient to experiment upon, from the faintness of its light; and, in effect, I found it was impossible to illuminate the field, so as to be able to see the wires without rendering the violet end of the spectrum invisible. I therefore observed with faintly illuminated wires on a dark field; and, instead of making contacts with the wires at different points of the spectrum, I varied the mode of observation, by carefully adjusting the wires to the breadth of the spectrum at its red end, and then "sweeping" its whole length. The wires seemed to *fit* the spectrum equally well at all points, so that no variation in breadth could be detected.

In order to avoid the difficulty of observing a faint spectrum, and at the same time to obtain a flame which would remain sensibly of the same size for a considerable time, I devised the following method. Volatile liquids, such as naphtha or turpentine, seemed preferable to the fixed oils, because, from their greater fluidity and freedom from viscid matter, they flow more freely through a cotton wick, and less rapidly impair its transmitting power; while from their volatility, and consequent rapid evaporation, the wick remains cool, and is scarcely at all burned. Both conditions are highly favourable to the maintenance of a constant

* It may be proper, in order to explain the different values for the same line of the spectrum in the different sets of observations, to remark that these were made on different days, and on flames of different dimensions.

flame. There was, however, an inconvenience to be anticipated. Most of the hydro-carbons which burn brightly, such as turpentine, are so rich in carbon that they produce a very smoky flame; and when they are employed to give light, as in the common camphine and paraffine oil lamps, special arrangements are needed for consuming their smoke by directing a powerful current of air against the flame. It was not convenient to adopt any of these arrangements; and it occurred to me that I should obtain a smokeless, but sufficiently brilliant flame by burning a mixture of two liquids, the one rich, and the other poor, in carbon, such as turpentine (C_5H_4) and alcohol ($C_4H_6O_2$). The liquids I selected were common coal naphtha and wood spirit; and I found that a mixture of about three volumes of commercial wood spirit to one volume of coal naphtha produces a flame neither less brilliant, nor more smoky, than that of an ordinary wax taper.*

I may remark, that, for the purpose I had in view, there seems no objection to the use of such a compound liquid as I have described; for I have shown elsewhere that all the hydro-carbons in burning produce similar spectra,—the only difference being, that the spectrum produced by the incandescent solid carbon, or by the envelope of the flame, is brighter in some cases than in others.

The following tables contain the observations made on the flame of a mixture of coal naphtha and wood spirit:—

OBSERVATIONS OF THE FLAME OF COAL NAPHTHA AND WOOD SPIRIT.†

First Set of Observations.

Line B.	Line b.	Line G.
130	138	133
I.‡ 135	II. 135	III. 130
134	136	131
138	140	129
VI. 135	V. 139	IV. 140
136	133	133
Means 134·07	136·83	132·67

Mean observed breadth of spectrum = 134·72.

* This flame might be used for household purposes, and probably also with advantage in experiments where an invariable source of light is wanted. The liquids, although both smell disagreeably, emit no perceptible odour in burning.

† Each number in this and the following table is a single micrometer reading.

‡ The observations in this and the following table, on the various lines of the spectrum, were made in the order of the numbers I., II.....VI., in order to eliminate the effect of any gradual change in the dimensions of the flame.

Second Set of Observations.

Line B.		Line b.		Line G.	
	125		127		127
I.	126	II.	126	III.	124
	125		128		128
	124		129		127
VI.	130	V.	130	IV.	127
	130		130		124
Means	126.67		128.33		126.17

Mean observed breadth of spectrum = 127.06.

In the following tables the above numbers have been corrected by subtracting the index error of the micrometer = 6.52.

Comparison of Observations.

Mean Breadth.	First Set of Observations.		Second Set of Observations.	
	128.20	Difference from Mean Breadth.	120.54	Difference from Mean Breadth.
Breadth at B, .	128.15	-0.05	120.15	-0.39
„ b, .	130.31	+2.11	121.81	+1.27
„ G, .	126.15	-2.05	119.65	-0.89

*The Observed Dimensions of the Flames reduced to inches.**

Mean Breadth.	First Set of Observations.		Second Set of Observations.	
	.20493	Difference from Mean.	.19268	Difference from Mean.
Breadth at B,	.20484	-.00009	.19206	-.00062
„ b, .	.20830	+ .00337	.19471	+ .00203
„ G, .	.20167	- .00326	.19126	- .00142

* These dimensions were derived from the numbers in the preceding tables by multiplying by 0.0016, the value of a micrometer division in inches; and that was ascertained by observing an accurate inch ivory scale placed in contact with the slit through which the flame was viewed.

These observations completely verify the results obtained with the flames of coal-gas and of alcohol. It will be seen that the greatest observed difference in breadth between the red and blue regions of the spectrum was only $\cdot 003$ inch, a discrepancy fairly within the limits of errors of observation. The observations, therefore, lead to the conclusion, that the structure which Professor DRAPER supposes to occur in flame has really no existence.

The question now arises, how are we to explain the inequality in breadth of the spectrum, as observed by him? There seems certainly considerable difficulty in accounting for the "rapid inclination of the sides at the red end of the spectrum," which he describes. From the effect of irradiation, every spectrum will appear slightly broader towards the middle, where the light is more brilliant, than towards the ends where it is comparatively feeble; a fact illustrated by my own observations, which exhibit a greater observed breadth at the line *b* of the spectrum than at the lines B and G. Now, as the brightest point,—about the line D,—occurs in the spectrum of a flint-glass prism much nearer the red than the violet extremity, the variation in brightness will be much more rapid from the extreme visible red rays to the line D, than from the line D to the extreme violet rays. Hence we may expect any apparent inequality of breadth, due to irradiation, to be most conspicuous at the red end of the spectrum, where the brightness of the light varies most rapidly. I have not, however, observed any contraction in breadth at the red end of the spectrum, which I should describe as "rapid;" and any notable contraction certainly did not extend beyond the line B.

The apparent want of parallelism which Professor DRAPER conceives he has discovered by instrumental means in the more refracted portions of the spectrum admits however of an easy explanation, if I have rightly understood his method of observation. It will be recollected that this seems, from his description, to have consisted in measuring the difference of azimuths of the two sides of the spectrum. Now, such a process could not fail to give erroneous results; for it may be easily shown, that if

d = the angular horizontal breadth of the spectrum at any point,

z = the zenith distance, and

θ = the observed difference of azimuths of the sides of the spectrum,

$$\sin \frac{1}{2} \theta = \sin \frac{1}{2} d \operatorname{cosec} z;$$

or if d and θ be small,

$$\theta = d \operatorname{cosec} z.$$

Now, z varies from point to point of the spectrum; whence the observed breadth θ would also vary, even although the true breadth d remained constant.

Moreover, the flame would probably be placed about the same level with the observer's eye, so that its zenith distance, when viewed directly, would be nearly 90° . According, therefore, as the light was refracted upwards or downwards, z

or $180^\circ - z$ would be least, and consequently θ would be greatest, for the most refrangible rays: and the spectrum would appear wider towards the more refracted end.

This may possibly explain the difference of breadth in the more refracted regions, as actually observed by Professor DRAPER—a difference confessedly *small*—even although irradiation, by increasing the apparent breadth of the brighter and less refrangible regions of the spectrum, must have produced a slightly compensating effect.

I must not omit referring here to one of Professor DRAPER's observations, which I have completely verified, namely, the greatly superior breadth of the yellow line R of FRAUNHOFER, when observed by his method, compared with the rest of the spectrum. The reason he assigns for this striking phenomenon is unquestionably correct, namely, that the homogeneous yellow light of a flame proceeds from its envelope. It must not be supposed, however, that this fact affords the slightest evidence in favour of his peculiar views regarding the constitution of flame; for I have elsewhere shown,* that the *envelope* of a flame produces light of *all* degrees of refrangibility between the limits (nearly) of the lines D and G of FRAUNHOFER, while rays of precisely the *same* degrees of refrangibility are produced by the *bright interior* conoid of the flame.

I will now advert to an objection which I can imagine may be made to the conclusion I would derive from my observations. It may be argued, that if such a connexion exist between the temperature of combustion, and the refrangibility of the resulting light, as Professor DRAPER assumes, and if he be correct in thinking that the temperature of a flame increases from the interior to the exterior, then there must be a series of strata of different colours, even although observation may fail in detecting them. To this I would reply, that the instrumental means I have employed were certainly capable of detecting any such structure, provided its thickness was not much less than $\cdot 005$ inch; and if we suppose it confined to such narrow limits, it must cease to be regarded as the general structure of the flame, whose walls greatly exceed such a thickness. If, moreover, we adopt the notion of such an extremely thin stratum of varying colour, it will be difficult to imagine so great a variation of temperature from point to point of its very small thickness as will be necessary to produce the corresponding diversity of colour, which is supposed to exist.

Having now shown that a careful series of experiments have failed to afford any evidence in favour of Professor DRAPER's theory of the constitution of flame, I will next examine the reasoning by means of which he endeavours to demonstrate his views *a priori*. It seems to me that he makes two quite gratuitous assumptions. If we refer to his experiments on the "Production of Light by

* Edinburgh Transactions, vol. xxi., p. 71.

Heat,"* we shall find that an ignited slip of platinum, at the temperature of 1210° Fahrenheit, produced a spectrum extending from the line B nearly to the line F of FRAUNHOFER. Hence the supposed innermost ring of a flame which produces light of no higher refrangibility than that of the line B, ought, on Professor DRAPER'S principles, to have a considerably *lower* temperature than the platinum slip. Now, considering the well-known extremely high temperature of flame, are we entitled to assume that any luminous portion of it has so low a temperature as 1210° of Fahrenheit?

If, further, we examine the experiments which Professor DRAPER adduces to prove that increased temperature produces light of increased refrangibility, we shall find that these were either observations of the spectra produced by a strip of platinum whose temperature was varied by transmitting through it a voltaic current of varying power, or observations of the spectra arising from a piece of ignited charcoal brought to a high temperature by means of a stream of oxygen, and then allowed to cool. It was found, in either case, that, as the temperature rose, rays of continually higher refrangibility were produced, which in their turn successively disappeared as the temperature fell. It must, however, be borne in mind that rays of *high* were always accompanied by rays of *low* refrangibility. Thus, when the temperature of the platinum rose from 1210° Fahrenheit to 2130°, the spectrum lengthened from the line F to the line H of FRAUNHOFER; but at *both* temperatures it reached to the line B in the *red*; and, at the *higher* temperature, it actually extended *farther* than at the lower, towards the extreme red rays of the solar spectrum. It therefore follows, that the higher the temperature, not only the *more* refrangible, but the *less* refrangible are the rays which are produced. This fact, most important in its bearing on the question we are discussing, seems to have been completely overlooked by Professor DRAPER in his speculations on flame. Assuming that a point at the outer surface of a flame is of higher temperature than one inside, he argues that the outer point will produce rays *exclusively of a certain high degree of refrangibility*, while the inner point will produce *less refrangible rays*; while the correct deduction from his experiments simply is that the outer point will produce a *more extended spectrum* than the inner. The outer point might alone produce light of high refrangibility; but both in common would produce light of low refrangibility. Professor DRAPER'S method of analyzing flame would therefore fail in exhibiting a spectrum with converging sides; for the extreme red rays would be emitted by the outer as well as by the inner regions of the flame; and, consequently, the red end of the spectrum would be of the same breadth as the violet. All, therefore, which can be fairly deduced from his principles is, that the outer regions *may* produce a longer spectrum and a brighter light than the inner; but there seems great reason to doubt whether

* Philosophical Magazine, vol. xxx., p. 349.

the difference of temperature at different points of a flame be really so great as to affect the quality of the light to an appreciable extent.

This will appear, if we adopt a method of examining flame, much simpler than prismatic analysis, and, for the purpose, probably more delicate. I mean simply looking at the flame. If the doctrine of concentric rings of various colours were really true, we should perceive, on looking through the flame in a line passing near its centre, the resultant tint due to the combination of all the colours in nearly equal proportions. But if we looked through the edge of the flame, the line of vision would cut each successive coloured ring more and more obliquely as it passed towards the interior of the luminous matter. We should therefore look through a greater thickness of the inner rings than of the outer. The result would be to give a preponderance to the inner tints, so that the apparent colour of the flame would vary from the middle towards the edges, at first slowly, then more rapidly, until at length, at the edges, we should see only the colour of the very outermost ring. I have failed to detect any such variation of colour in the flames I have examined. I therefore infer that each of the three conoids of a hydro-carbon flame has sensibly the same tint throughout its entire thickness.

In my paper on the spectra of the flames of the hydro-carbons, I have described experiments which lead to the same conclusion, but to which I can only here refer, without entering into details. There is, however, one experiment, which is easily performed, and which I have not before described. By holding a piece of plate-glass over the smokeless flame of a Bunsen lamp, and looking downwards through the glass, a tolerably good horizontal section of the flame is obtained. It is then seen that both the inner blue cone and the envelope of the flame are sensibly homogeneous in colour throughout their entire thickness.

We may also verify a conclusion which I have stated in the paper already referred to, namely, that when common salt is placed in a flame, the envelope alone becomes yellow, while the inner blue cone remains unaltered in colour. This is strikingly apparent on looking down in the manner described, and introducing salt into the flame. The outer mantle changes at once from purple to bright yellow, while the inner blue conoid remains quite unaltered in tint; and this is the case, whether the salt is brought into contact with the outer mantle or the inner conoid. Possibly this phenomenon may be explained by supposing that the sodium of the salt is reduced to the metallic state by the free hydrogen of the inner conoid, and that its vapour burns exclusively in the outer mantle, producing the yellow tint only in that region of the flame.