



XVI. On the production of light by chemical action

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seeking the development, to take the more general form a^{x+h} , $\log(x+h)$, &c., and to proceed as above, afterwards making $h=0$; for we shall thus always be led to true developments, and thence to the cases in which the sought developments are impossible, these being indicated by the hypothesis of $h=0$ causing the coefficients to become infinite. And it is obvious, from the method above described, that the coefficients of the development of $F(x+h)$ are just as readily obtained as those derived from $F(x)$ in the usual way.

In thus recommending that x be replaced by $x+h$, when the development of $F(x)$ is required in powers of x , it will be observed, from what is said above, that it is merely proposed to deduce D_0, D_1, D_2 , &c. from $F(h)$. If these are infinite when $h=0$, the inference will be, that, *with finite coefficients*, the development is impossible. But if we leave h undetermined, and put, in the series, $x-h$ for x , we shall then get the development of $F(x)$, with finite coefficients, in powers of $x-h$; and as h is arbitrary, we may thus approach as near to the proposed development as we please. And although for the purposes of actual numerical computation, the coefficients would become more and more unmanageable, from their increasing magnitude, as h approaches to zero, yet even in this extreme case—in which the coefficients actually become infinite—the development, regarded as the last of the series of developments here spoken of, will still be analytically true.

Belfast, Jan. 5, 1848.

XVI. *On the Production of Light by Chemical Action.* By JOHN WILLIAM DRAPER, M.D., Professor of Chemistry in the University of New York*.

THE production of light and heat by the combustion of various bodies is, of all chemical processes, that which ministers most to the comfort and well-being of man. By it the rigour of winter is moderated, and night made almost as available for our purposes as the day.

One would suppose that, of a phenomenon on which so much of our personal and social happiness depends, and which must have been daily witnessed by every man that has ever lived, all the particulars ought to have been long ago known. Among scientific men its importance has been universally recognized. The early theories of chemistry, such as those of Stahl and Lavoisier, are essentially theories of combustion.

It is nevertheless remarkable how little positive knowledge we still possess on this subject. Some chemists believe that

* Communicated by the Author.

the light emitted by flames is due to electric discharges; others, regarding light and heat as material bodies, which can be incorporated or united with ponderable substances, suppose that they are disengaged as chemical changes go on. In this confusion of opinions, a multitude of interesting and hitherto unanswered questions present themselves. It is known that different substances when burning emit lights of different colours: thus sulphur and carbonic oxide burn blue, wax yellow, and cyanogen lilac. What are the chemical conditions that determine these singular differences? How is it that, by changing the circumstances of combustion, we can vary the nature of the light? We turn aside the flame of a candle by means of a blowpipe, and a neat blue cone appears; why does it shine with a blue light?

Such inquiries might be multiplied without end; but a little consideration shows that their various answers depend on the determination of a much more general problem; viz. *can any connexion be traced between the chemical conditions under which a body burns, and the nature of the light it emits?* It is to the discussion of that problem that this memoir is devoted.

Sir H. Davy has already furnished us with two important circumstances in relation to the nature of flame:—1st. All common flames are incandescent shells, the interior of which is dark; 2nd, the relative quantity of light emitted depends on the temporary disengagement of solid particles.

It is only by a very general examination of the light arising from various solids, vapours and gases, when burning, that we can expect to obtain data for a true theory of combustion. This is what I shall endeavour to furnish on the present occasion.

As was foreseen by all the older chemists, the true theory of combustion, whatever it may prove to be, must necessarily be one of the fundamental theories of chemistry. It must include the nature of all chemical changes whatsoever. The subject is therefore not alone interesting in a popular sense, but of great importance in its scientific connexions.

I. Prismatic analysis of the flames of various vapours and gases; proving that they yield all the colours of the spectrum.

I commenced this investigation of the nature of flame, and of combustion generally, by an optical examination of various bodies in the act of burning. Some authors have asserted that certain flames yield monochromatic lights. It is necessary to verify this assertion if true, or set it aside if false.

The instrumental arrangement which I have employed is as follows:—The rays of the flame, of which the examination is to

be made, pass through a horizontal slit $\frac{1}{30}$ th 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.

If it be the flame of a lamp of any kind that is to be examined, by using a moveable stand we are able to raise or lower it, and thus analyse different *horizontal elements* in its lower, its middle, or its upper part at pleasure. If, instead of a horizontal, we wish to examine a *vertical element* of the flame, the slit and the prism must of course be set vertically. The former mode possesses great advantages, as will be presently pointed out. It is to be understood, in all cases, that the eye-piece of the telescope is adjusted to give a sharp image of the slit, and the prism is at its angle of minimum deviation.

By this arrangement I have examined a great number of different flames; as those of oil, alcohol, solution of boracic acid and nitrate of strontian in alcohol, phosphorus, sulphur, carbonic oxide, hydrogen, cyanogen, arseniuretted hydrogen, &c. Among these it will be noticed different colours occur. Oil gives a yellow flame, alcohol a pale blue, boracic acid green, strontian red, phosphorus yellowish-white, sulphur and carbonic oxide blue, hydrogen pale yellow, cyanogen lilac, arseniuretted hydrogen white, &c.

Notwithstanding this diversity of colour, all these flames, as well as many others I have tried, yield the same result: *every prismatic colour is found in them*. Even in those cases where the flame is very faint, as in alcohol and hydrogen gas, not only may red, yellow, green, blue, and violet light be traced, but even bright Fraunhoferian lines of different colours.

This observation holds good for those flames reputed to be monochromatic; for example, alcohol burnt from a wick imbued with common salt. It is not alone a yellow light which is evolved; the other colours plainly, though more faintly, appear.

All flames, no matter what their primitive colours may be, evolve all the prismatic rays. Their special tints arise from the preponderance of one class of rays over another; thus in cyanogen the reds predominate, and in sulphur the blues.

The production of light, in the case of flames, is thus proved to be a very complex phænomenon. The chemical conditions under which their burning takes place are likewise very complex. The combustible vapour is surrounded on all sides by atmospheric air: diffusion occurs, and rapid currents are

established by the high temperature. Such circumstances complicate the result; and it is only by observing the burning of an elementary solid, in which most of these disturbances are cut off, that we can hope to effect a proper resolution of the problem.

II. *Prismatic analysis of the light of an elementary solid burning at different temperatures; proving that as the temperature rises the more refrangible rays appear.*

I took from the fire a mass of anthracite coal, the fuel ordinarily used in domestic economy in New York, and which from its compactness, the intense heat it evolves, and other properties, appears to be well-fitted for such investigations as the present. This coal was placed on a support, so as to present a plane surface to the slit in the metal screen. The rays coming from it and passing the slit were received on a flint-glass prism, and viewed through the telescope.

When the coal was first taken from the fire, and was burning very intensely, on looking through the telescope I saw all the coloured rays of the spectrum in their proper order. I had previously passed through the slit a beam of sunlight reflected from a mirror, that I might have a standard spectrum with fixed lines. Now when the coal was burning at its utmost vigour, the spectrum it gave did not seem to me to differ either as respects length or the distribution of its colours from the spectrum of sunlight; but as the combustion declined, and the coal burnt less brightly, I saw that its spectrum was becoming less and less, the shortening taking place at the more refrangible extremity, one ray after another disappearing in due succession. First the violet became extinct, then the indigo, then the blue, then the green, until at last the red, with an ash-gray light occupying the place of the yellow was alone visible, and presently this also went out.

From numerous experiments of this sort, I conclude 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.* It may perhaps be objected by some, that, in the form of experiment here introduced, two totally different things are confounded; and that the burning coal not only gives forth its rays as a combustible body, strictly speaking, but also as an incandescent mass.

To avoid this objection as far as possible, and also to reach a much higher temperature than could have been otherwise obtained, I threw a stream of oxygen gas on that portion of the anthracite which was opposite the slit; but my expect-

tations were disappointed ; for instead of the combustion being increased, the coal was actually extinguished by the jet playing on it. I therefore replaced the anthracite with a flat piece of well-burnt charcoal, kindled at the part opposite the slit, and throwing a stream of oxygen on this part, the combustion was greatly increased ; and through the telescope I saw a spectrum rivalling that of the sunbeams in brilliancy, all the colours, from the extreme red to the extreme violet, being present.

Now on shutting off the supply of oxygen the combustion of course declined ; and whilst this was going on, I looked through the telescope and saw the violet, the indigo, the blue, the green, &c. fade away in succession. By merely turning the stopcock, through which the oxygen came, I could re-establish the original colours or witness their decline. And it was very interesting to see with what unerring regularity, as the chemical action became more intense, the more refrangible colours were developed ; and how, as it declined, they disappeared in due succession ; the final tint being red, and that ash-gray in the position of the yellow, which I have described in my former memoir. (*Phil. Mag.* May 1847, p. 349.)

In the form of experiment here made the combustion is of course merely superficial ; and the rays come from the charcoal, not as an incandescent, but as a burning body.

III. *Of the constitution of flames ; proving that they consist of a series of concentric and differently coloured shells.*

I regard the foregoing experiments as affording the means of explanation of the much more complicated phenomena of flames ; and proceed to inquire whether the principle I have just brought forward, of the co-ordinate increase of refrangibility and chemical action, will hold good, premising the experiments now to be detailed with the following considerations.

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 certain 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 results of the foregoing experiments with anthracite coal and charcoal to be true, viz. that as combustion is more active rays of a higher degree of refrangibility are evolved, 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; and when those compound rays are received on the face of a prism, the constituent colours are parted out, by reason of their different refrangibility, and the eye thus made sensible of their actual existence.

When thus, by the aid of a prism, we analyse the light that comes from any portion of the superficies of a flame, we in effect dissect out in a convenient manner, and arrange together side by side, rays that have come from different strata of the burning shell. These, without the prism, would have pursued the same normal path, and produced a commixed effect on the eye, but with it are separated transversely, and each becomes perceptible.

It might be supposed that, in the familiar instance of an oil-lamp, if we put any check on the supply of the air and thereby check the intensity of combustion, we ought to have the flame emitting rays of light, the refrangibility of which becomes less and less, and which, from their being quite white, should pass through different shades of orange, and end in a dull red. But the compound nature of the burning vapour interferes with that result; for when a certain point is gained, the hydrogen for the most part alone burns, the carbon being set free as smoke, and such a flame cannot support itself in strict accordance with the principle given.

We must then search for other conditions under which carbon is found which are free from this difficulty. Two at once present themselves; they are carbonic oxide and cyanogen gas. In the former the carbon is already united with half the quantity of oxygen required for maximum oxidation, its complete combustion can therefore be carried on with a limited supply of atmospheric air; in the latter the carbon is united with nitrogen, which during combustion is set free, and interferes with the process by cutting off the more complete access of the atmosphere.

In place of the burning coal of the former experiments I

substituted a jet-pipe, through which the various gases might be made to pass, and the rays emitted by their flames enter the telescope after passing through the slit and prism. 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 increasing breadth proves that the constituent coloured shells of the flame envelope each other, the violet being outermost and therefore broadest. This valuable indication would be wholly lost if the slit was vertical.

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 toward 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 coincide with first one and then the other side of the spectrum. It will be understood that I took the proper precaution not to be deceived by a partial want of achromaticity in the telescope, which might have led to a mistake.

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 re-

calling 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. This, which is readily seen when the flame is large, envelopes the middle and upper parts, but cannot so easily be detected low down. It is to be attributed to the carbonic acid and steam that have risen at a high temperature in the burning shell, and are escaping at a degree above that of incandescence into the air, and are mingled with oxygen diffusing from the air into them. A similar tawny cloak surrounds the upper part of the flame of a candle; it answers to the oxidizing flame of the blowpipe, and yields Brewster's monochromatic yellow light.

IV. *Explanation of the nature of coloured flames; showing, for example, why carbonic oxide burns blue, and cyanogen red.*

To return now to carbonic oxide and cyanogen. Fig. 1. No. 1 represents the solar spectrum with its fixed lines; No. 3

Spectra of various flames. Fig. 1.

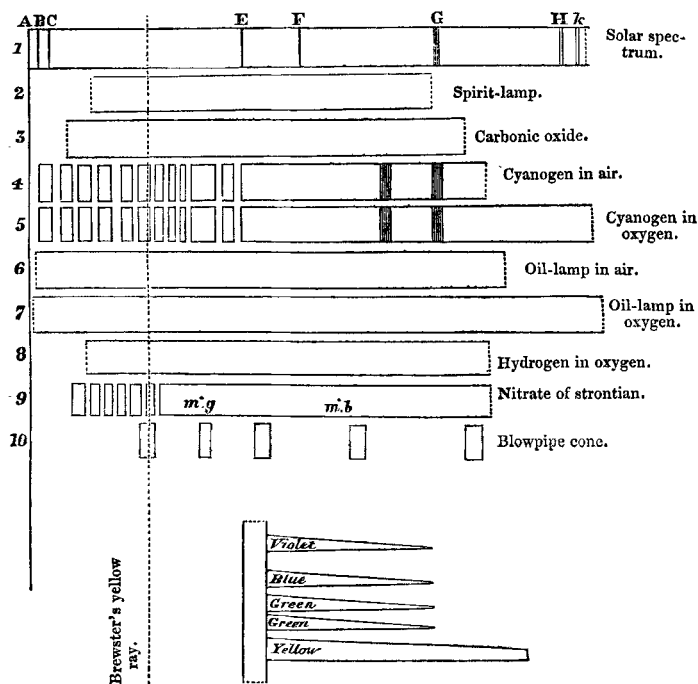


Fig. 2. *Air in the interior of a flame.*

represents the spectrum of carbonic oxide burning in the air. It begins in the red region short of the fixed line C, and terminates between the lines G and H. It yields therefore rays of every colour; and this is in accordance with the principles I have laid down; but when the relative quantity and force of the rays are estimated, in comparison with the sunlight spectrum, the red and orange are deficient, and the more refrangible colours predominate, and indeed it is the excess of these that gives the flame its characteristic blue tint. This agrees with what has been observed as to anthracite and charcoal; for with carbonic oxide a very limited supply of oxygen can bring about the maximum chemical action, and therefore liberate in abundance rays of maximum refrangibility.

This condition of things is inverted in the case of cyanogen gas. It is the nature of its flame to be enveloped, as it were, in a sheet of nitrogen arising from its own burning; and this necessarily impedes the access of air, and checks the intensity of the chemical change; a check which is at once betokened by the emission of a predominant number of rays of low refrangibility, or of a red colour.

But there is a striking difference in the chemical conditions under which carbonic oxide and cyanogen burn. In the case of the former the whole gas is combustible, in the latter the carbon alone; and we have in reality introduced an incombustible element into the flame; for as the carbon burns, the incombustible nitrogen is set free. It occurred to me, in selecting this gas for experiment, that this condition should impress a physical characteristic on the flame. I thought it was not impossible that dark lines in its spectrum might be the result; because there must be a peculiar arrangement of the burning strata, which together make up the shell of the flame, every two atoms of carbon setting free one of nitrogen. I did not know until subsequently that this flame had already been examined by Mr. Faraday. Having therefore confined some cyanogen, made from the cyanide of mercury, in a glass gas-holder, which was filled with a saturated solution of common salt, I burnt it from the jet-pipe, and found that what I had surmised was actually the fact. There was a spectrum so beautiful, that it is impossible to describe it by words or depict it in colours. It was crossed throughout its extent by black lines, separating it into well-marked divisions. I could plainly count four great red rays of definite refrangibility, followed by one orange, one yellow, and seven green; whilst in the more refrangible spaces were two extensive groups of black lines, recalling somewhat from their position, but greatly exceeding in extent, Fraunhofer's lines marked G and H in the

sun rays. I shall return to the consideration of this spectrum and to the nature of fixed lines presently; here only making the remark, that the burning of cyanogen, both as respects the colour of the light and the occurrence of fixed lines, is a direct consequence of the principle I am establishing.

The unassisted eye detects two well-marked regions in the cyanogen flame; a greenish-gray stratum on the outside, and a lilac-coloured nucleus within. Decomposed by the prism, a horizontal element of this flame shows that the exterior shell contains all the prismatic colours, except perhaps the yellow; but the green, the blue, and the violet greatly predominate. The interior lilac flame is the source of the bright spectrum with fixed lines just described.

V. Continuation of the same principle in the case where combustion is carried on in oxygen gas instead of atmospheric air.

If the principle that high refrangibility is connected with intense chemical action be true, it must hold good when the nature of the atmosphere in which the burning is carried forward is changed. If instead of being the common air it is oxygen gas, we ought to be able to foresee the result. Carbonic oxide, when made to burn in that gas, should not change its tint; because if the air can carry on the process to its maximum effect, oxygen can do no more. But the result should be just the reverse with cyanogen, which, if made to burn in oxygen, should be capable of emitting rays of higher refrangibility.

Foreseeing this result, I proceeded to submit the two gases to the test of experiment, and first arranged the carbonic oxide that its spectrum might be examined in the telescope as already described; then causing a clean bell-jar full of oxygen to be inverted over it, the flame diminished somewhat in size, emitted a slight crackling sound, *but retained its colour unchanged*. Its spectrum appeared precisely the same, both as respects extent and the distribution of colour, whether the burning took place in oxygen gas or in the atmospheric air.

If cyanogen be made to burn in oxygen, we should expect that it would lose to a great extent its characteristic lilac tint, and emit a whiter light. It was therefore very interesting to find, that the moment the flame was immersed in oxygen it lost much of its pinkish colour, and became of a dazzling brilliancy: and on examination through the telescope, though all the colours had increased in brightness, the most remarkable effect took place among the extreme refrangible rays. Far out of the limits of the ordinary spectrum, a ray of great

purity and force was developed, as represented in fig. 1, No. 5. Its colour is violet.

I have made similar experiments on many other flames besides those here mentioned. It is not necessary to relate them in detail, for they give the same results. In every instance of combustion in the air, when the flame is bright enough, all the colours are visible; and when the combustion takes place in oxygen, they are increased in intensity. With hydrogen gas and alcohol, the light is so feeble that the eye cannot catch the terminal rays; but as soon as the combustion is made in oxygen, the red and the violet both appear, the latter however predominating. Several of these spectra, both in air and oxygen, are represented in fig. 1. In No. 9, the letters *mg* and *ml* indicate a maximum of green and of blue light in the form of bright lines.

It does not require the use of a prism to satisfy oneself of the change of tint that flames exhibit when the chemical action increases. In reality it is only necessary to contrast the colour of the light emitted in air and oxygen gas. In the latter case rays of a higher refrangibility uniformly arise.

On the evidence furnished by the foregoing experiments, I regard all flames as consisting of a shell of ignited matter in which combustion is going on with different degrees of rapidity at different depths, being most rapid at the exterior where there is a more perfect contact with the atmosphere, and diminishing inwards. In a horizontal section, the interior space, consisting of unburnt vapour, is black; this is surrounded by a ring where the combustion is incipient, and from which red light issues; then follow orange, yellow, green, blue, indigo, and violet circles in succession, the production of each of these tints being dependent on the rapidity with which chemical action is going forward, that is, on the amount of oxygen present; the tints gradually shading off into one another, and forming, as I have already said, a circular rainbow. An eye placed on the exterior of such a flame, sees all the colours conjointly, and from their general mixture arises the predominant tint.

An examination of the flame of a candle *vertically* confirms this conclusion; for the red projects on the top of the flame, and the blue towards the bottom.

From this, which may be regarded as the normal flame, the flame of cyanogen differs. It must consist of as many concentric shells as the prism separates it into regions of definite refrangibility. The interior part is therefore divided into four red layers, followed by one of orange, one of yellow, seven of green, &c. There are two great inactive spaces towards the

outside of the flame, corresponding to the two great groups of fixed lines. Perhaps through all these inactive parts the incombustible nitrogen chiefly escapes.

VI. *Effects of the introduction of air into the interior of a flame, producing the destruction of the red and orange strata, and converting them into violet.*

It now becomes a curious subject of inquiry to determine what must take place when an ordinary flame is disturbed by the introduction of air into its interior. When a blowpipe jet is thrown through the flame of an oil-lamp, the sharp blue cone which forms, indicates, on the principles here set forth, that the combustion is much more active. But if the colours of a common flame come from different depths, the red being the innermost, it is clear that the introduction of a jet of air by a blowpipe should make the combustion rapid where before it was slowest, and the less refrangible colours ought to be destroyed. A prismatic analysis should exhibit the spectrum of a blowpipe flame without any red or orange.

In this examination no slit is required, as in the former experiments, for the cone itself when at a distance of six or eight feet is narrow enough for the purpose: it yields a very extraordinary spectrum. As was anticipated, I found that all the red rays were gone, and not a vestige of either them or the orange could be seen. But the spectrum was divided into five well-marked regions, separated from one another by inactive spaces; in short, I saw five distinct images of the blue cone, one yellow, two greens, one blue, and one violet. In fig. 1, No. 10, this result is represented.

This experiment may be verified without a telescope. On looking through a prism set horizontally at its angle of minimum deviation, at the blowpipe cone some six or eight feet distant, there will be seen a spectrum of that part of the flame which does not join in the production of the blue cone. It contains of course all the prismatic colours. But projecting from this are five coloured images of the cone; one yellow, two greens, one blue, and one violet. They are entirely distinct from one another, and are parted by dark spaces, fig. 2. (p. 107.)

Such is the effect of introducing air into the interior of a flame and destroying those strata that yield the red and orange colours. The effect of a blowpipe is to produce a double stratum of blue light, one being external, the other internal; also two strata of green, one again external, the other internal; and the escaping products of combustion, steam and carbonic acid, mingled with atmospheric air, constitute the oxidizing flame which envelopes the blue cone and emits Brewster's

monochromatic yellow light. That the yellow light comes from this flame is proved by the greater length of its image.

VII. *Physical cause of the production of light by chemical action.*

Do not the various facts here brought forward prove that all chemical combinations are attended by a rapid vibratory motion of the parts of the combining bodies, which vibrations become more frequent as the chemical action is more intense?

The burning particles which constitute the inner shell of a flame are executing about four hundred billions of vibrations in one second; those in the middle about six hundred billions, and those on the exterior, in contact with the air, about eight hundred billions in the same time. The quality of the emitted light, as respects its colour, depending on the frequency with which those vibrations are accomplished, increases in refrangibility as the violence of the chemical action becomes greater.

The parts of all material bodies are in a state of incessant vibration: that which we call *temperature* depends on the frequency and amplitude of those vibrations conjointly. If by any process, as by chemical agencies, we increase that frequency to between four and eight hundred billions of vibrations in one second, ignition or combustion results. In the case of the former of these numbers the temperature is 977° F. At this temperature or epoch the waves propagated in the æther impress the organ of vision with a red light. *This also is the temperature of the innermost shell of a flame.* If the frequency of vibration still increases, the temperature correspondingly rises, and the light successively becomes orange, yellow, green, blue, &c., and this condition obtains in the successive strata of a flame as we pass from its interior to its exterior superficies.

The general principle at which I thus arrive, as the final result of this experimental investigation, viz. that there is a connexion between the vehemence with which chemical affinity is satisfied and the refrangibility of the resulting light, assumes the position of a simple consequence of the undulatory theory. Is it not very natural, if all chemical changes are attended by vibratory motions in the particles of the bodies engaged, that those vibrations should increase in frequency as the action becomes more violent? But an increased frequency of vibration is the same thing as an increased refrangibility.

I think that in this manner the theory of ethereal undulations is on the point of including many of those fundamental facts in chemistry which until now have been believed to be adverse to it, or at all events as standing apart from it. I recall the admirable remark which Mr. Whewell has made, in his *History of the Inductive Sciences*, how this theory, like

that of universal gravitation, has exhibited all the aspect of a great physical fact, advancing to the explanation of things that seemed to have no necessary connexion with it, and converting what at first sight was regarded as contradictory into the firmest arguments for its truth.

VIII. *On the physical cause of Fraunhofer's dark lines.*

Although I have extended this memoir to so great a length, I have omitted many facts which have been made the subject of experiment. I cannot however conclude without offering some remarks on the artificial production and cause of Fraunhofer's fixed lines.

It has already been related how I was led to expect the production of these lines in the flame of cyanogen, from considering the circumstances under which its combustion takes place. Returning to this phænomenon, I shall here point out a very remarkable numerical relation existing among the fixed lines of the solar spectrum.

The following table contains Fraunhofer's determination of the wave-lengths corresponding to the seven great fixed lines of the spectrum, which are designated by the capital letters of the alphabet from B to H. I have added the wave-length of A from my own experiments.

Table of wave-lengths corresponding to the eight great fixed lines of the solar spectrum, the Paris inch being supposed to be divided into one hundred millions of equal parts.

A =	2660
B =	2541
C =	2422
D =	2175
E =	1945
F =	1794
G =	1587
H =	1464

An examination of this table proves that

the wave length of B is 119 parts less than A

.....	C	238
.....	D	485
.....	E	715
.....	F	866
.....	G	1073
.....	H	1196

and these differences of length are obviously very nearly as the whole numbers 1, 2, 4, 6, 7, 9, 10. This coincidence is

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far too striking to be merely accidental. Moreover, it must not be forgotten that the observed numbers, as determined by Fraunhofer, are wholly independent of any hypothesis.

If the relation of whole numbers was rigorously true, the numbers in the foregoing table would stand as follows: 119, 238, 476, 714, 833, 1071, 1190.

The wave-length of the most luminous portion of the spectrum, the centre of the yellow space, is 2060 parts. If we take this as an optical centre, it will be found that the great lines are situated symmetrically in relation to it. E and D are equidistant above and below it; the same observation applies to G and B, and also to H and A. The only departure from this symmetry is in the case of F, which is not symmetrical with C. It will be understood that I am here speaking of one of those spectra which are formed when a grating or ruled surface is used. In this the colours are arranged side by side, according to their wave-lengths; the centre of the spectrum, which is its most luminous portion, is occupied by the centre of the yellow space, and the light terminates at equal distances in the violet and red.

Do not these observations lead us to conclude, that the cause, whatever it may be, that produces these fixed lines is *periodic in its action*?

What that cause in reality is, we have not now facts sufficient to determine. I would not affirm that the disengagement of incombustible matter by a flame will always give rise to dark lines. But this is very clear; that in all those cases, as cyanogen, alcoholic solutions of nitrate of strontian, of boracic acid, &c., in which these lines are developed, incombustible matter is uniformly disengaged.

University, New York,
Dec. 25, 1847.

XVII. *An Account of the Method of Vanishing Groups.* By JAMES COCKLE, Esq., M.A., of Trinity College, Cambridge; Barrister-at-Law, of the Middle Temple*.

IN a paper On certain Algebraic Functions just published in the Cambridge and Dublin Mathematical Journal, I have given a more detailed and connected view than I had previously done of the analysis which I have, since writing that paper, proposed to term the Method of Vanishing Groups. I have employed this analysis, perhaps not altogether without success, in the theory of equations and in analytical geometry; and I indulge a hope that the following little account of the

* Communicated by Dr. Nathaniel Lister, late Physician to St. Thomas's Hospital, &c.