

XV.—*The Structure and Chemistry of Flames.*

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DURING the past 12 months we have been engaged in investigating some new points in connection with the structure and chemistry of flames. The investigation, which at first proceeded rapidly, has latterly become more complex and difficult, and much more work is demanded for the complete solution of the problems that have arisen. We fully intended to delay the publication of our results until material for a complete memoir had been accumulated, especially as we believed ourselves to be working in an obscure corner of the subject. But in the *Journal für praktische Chemie*, 44, 246, there appeared a paper "Zur Kennzeichnung der Flamme," by N. Teclu, which was first brought to our notice by an abstract in this Journal (1891, 1309), and the paper gives a description of the very phenomenon which served as the starting point of our experiments. The author also, in a footnote, reserves to himself the investigation of the field to which this phenomenon opens the way. As the phenomenon in question was observed by one of us three or four years ago, and has indeed been since shown as a lecture experiment, and as we have been so long engaged in working out the points suggested by it, we feel compelled

to give an account of our experiments as far as they have gone, and to indicate the directions in which we propose to extend them. The greater part of the account which follows was, we may say, in manuscript before Herr Teclu's paper came under our notice.

The experiments to be described were undertaken with the general object of enquiring into the structure of hydrocarbon flames. By employing hydrocarbons of definite composition we hoped that it would be possible to trace the chemical changes taking place in different regions of the flame with more accuracy and definiteness than is possible with coal-gas, paraffin, or other mixtures such as have been used by previous investigators.

By something of the nature of an accident, the enquiry has been directed in the first instance to the study of non-luminous flames. A long, glass tube was fixed over a Bunsen burner so as to form practically a wider prolongation of the metal tube, and the ordinary non-luminous flame was obtained at the top of it. On diminishing the supply of gas or increasing the supply of air, such a flame assumes the well-known, clearly-defined, two-coned structure, the inner cone becoming gradually flatter and smaller, more sharply defined, and distinctly green in colour. If the gas supply be further diminished, the flame eventually passes down the glass tube, until after a period of rapid vibration it either causes the detonation of the mixture in the tube and lights the gas at the bottom, or else it goes out.

This experiment has been shown by Professor H. B. Dixon to illustrate the initiation of the explosive wave, and the phenomena observed are similar to those photographed and described by Mallard and Le Chatelier in their experiments on the same subject (*Bull. Soc. Chim.*, 39, 572; *Abstr.*, 1884, 46, 549).

An attempt was made to cause the retreating flame to register its course by coating the interior of the tube thinly with wax, and some interesting markings were obtained. We hold this matter in reserve for the time being.

On carefully regulating the supply of gas and air so that the flame would just, but only just, recede, it was found that the flame would pass down the tube for 12 inches or so, and then return to the top; and in this way an oscillation of the flame could be maintained for some minutes. On carefully inspecting the apparatus when in this condition, it was found that the flame did not recede as a whole, but that, in fact, it split into two parts (i), an inner cone which became flatter and greener as it entered the tube and descended the latter like a piston with a convex under surface, and (ii), a larger, scarcely-luminous, lilac-coloured cone which remained in its original position at the top of the tube. It was obvious that this division of the flame corresponded to the two-coned structure of a Bunsen flame, and the ex-

periment made it clear that in a Bunsen flame we have two distinct stages and areas of combustion defined respectively by the inner and outer cones of flame. The apparatus seemed to promise a means of widely separating these regions and of examining the gases between them without any possibility of diffusion of the outside air or of gases from other parts of the flame. For this purpose, it was necessary to devise some means whereby, after the flame had been divided into two cones, these could be kept separate whilst some of the gases from the interconal space was aspirated for analysis.

It will perhaps be well at this point to consider the reason for the division of the flame. When a Bunsen flame is burning at the top of a tube in the ordinary way, the coal-gas is in such excess that the mixture within the tube is scarcely explosive. If now the proportion of coal-gas to air be diminished, the mixture within the tube becomes more explosive, and the initial velocity of inflammation of this mixture increases as the proportion of air is increased up to a certain point. Long before enough oxygen is mixed with the gas for its complete combustion, the explosibility of the mixture has reached such a point that the velocity of inflammation is greater than the velocity of efflux from the tube, and so the flame is differentiated into two cones, one of which descends the tube and marks the margin of the explosive mixture. The other cone marks the area of combustion of the combustible gases which have escaped combustion in the lower cone, and are burning at the top of the tube in free air. Now the rate at which the inner cone will continue to descend the tube will depend upon several conditions, one of which is the temperature, another the diameter of the tube, and these considerations suggested a means of arresting the lower cone of flame. By heating the glass tube with a blowpipe flame at a point about a foot below the top, it was found possible to arrest the inner cone when *reascending*; the high temperature producing locally a velocity of inflammation greater than that at points above or below, and so fixing the flame. The second method suggested by the foregoing considerations was simply to diminish the diameter of the tube at one point either by means of a metal diaphragm or by slightly drawing out the tube so as to cause a constriction. At the narrow part of the tube, the velocity of the ascending gas mixture is obviously greater than elsewhere, and hence a flame which will descend the wider part of the tube will be arrested at this point. With this apparatus, the flame could be divided with the greatest ease, and the two regions of combustion kept separate for any length of time.

The apparatus finally adopted was constructed as shown in Fig. 1. A Bunsen burner A is fitted to a glass tube BC by means of a perforated cork or a packing of cotton wool. The upper part of this

tube is sheathed with a wider one EF, and connected to it by a joint at E.

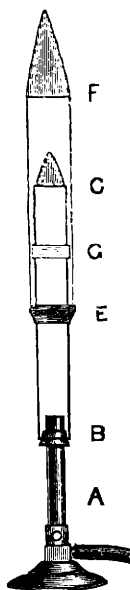


FIG. 1.

The most suitable joint for this purpose is an india-rubber tobacco-pipe cover, the flat disc of which can be punched out with a cork-borer so as to admit the inner tube. Whilst maintaining an air-tight connection, this admits of the free up and down movement of the inner tube.

The two tubes are kept coaxial by a ring of asbestos at G. Rings of brass foil may be fitted into the ends C and F of the glass tubes to diminish the risk of cracking by heat, and to avoid coloration of the flame by the sodium of the glass.

If the apparatus be arranged so that the mouth of the inner tube is about 10 cm. below that of the outer one, and the gas be lighted, an ordinary Bunsen flame is obtained at the mouth of the latter. If now the gas supply be gradually diminished, the flame becomes smaller, and the two-coned structure more evident until the inner cone, having become very small and green in colour, shows a tendency to enter the tube. As the gas supply is further cut off, the inner cone will probably descend and reascend a few centimetres, until finally it descends as far as the orifice of the inner tube at C, on which it will then suddenly settle and remain. This point is equivalent to a constriction in the tube, and the consequent increase in the velocity of ascending

gases determines the sudden arrest of the receding flame. Whilst this is going on, a feeble flame consisting of a single hollow cone of pale lilac colour remains at the orifice of the outer tube F. The two conical areas are thus widely separated, and the gases coming from the lower one can be easily aspirated by introducing one limb of a bent tube at F.

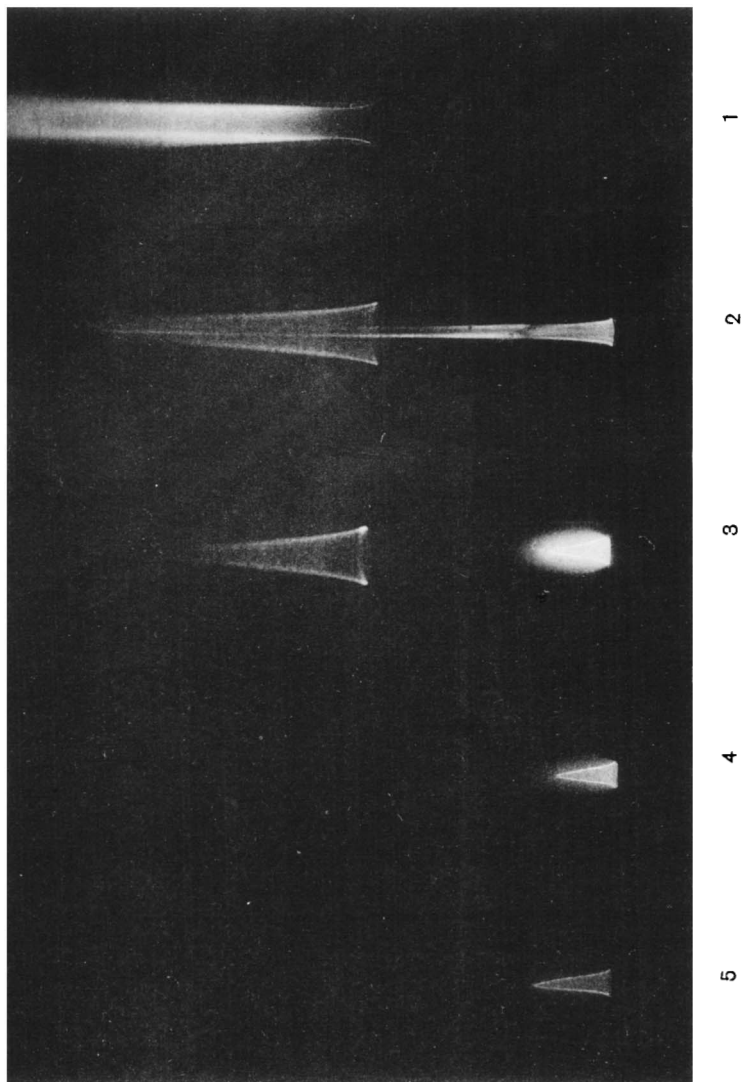
That these two cones correspond to the two cones of a Bunsen flame is evident from the course of the experiment, but it may be seen still more plainly by modifying the procedure as follows :—The apparatus is arranged so that the inner tube projects above the outer one, and the Bunsen flame is obtained on the former. The gas supply is then cut off till the inner cone is on the point of descending, but is still burning steadily. The outer tube is then slid slowly up beyond the inner tube, and it will be seen to cleanly detach and carry up the outer cone from the inner one, which remains in its original position at the top of the inner tube.

An idea of the distribution of heat may be obtained by stretching an iron wire along the axis of the two tubes, when it will be seen that the brightest glow is where the wire passes through the top of the lower cone. Below and above this point the wire remains dark until it passes through the tip of the upper cone. It is evident that both cones are hollow, and that the lower one is much the hotter. Its temperature appears to lie between the melting point of copper and iron, that is, above 1300°.*

Instead of using the apparatus as shown in Fig. 1 (the handiest form for a lecture experiment), it has been found more convenient to dispense with the Bunsen burner, and to have the supplies of gas and air under complete control; and to this end the gases have been forced in from gas-holders through a T-piece passing through a cork at B. This arrangement also allows the experiment to be carried a stage further. If, after the air and gas have been adjusted so as to produce a separation of the cones as above described, the supply of air be further increased, the explosibility of the mixture increases, the inner cone darts down, the upper one disappears, and the combustion goes on at B, where the gases enter the apparatus. On further increasing the air-supply, the flame goes out, but a little more air now *diminishes* the explosibility of the mixture, and it is found possible to ignite it when it burns in a simple cone at C. This is a flame burning with excess of air, and, being no longer a seat of

* Rosetti (*Ber.*, 1877, 2054, and 1878, 809) gives the temperature of the inner cone of an ordinary Bunsen burner as below 1200°, and the highest temperature outside it as 1360°. According to Bunsen ("Flammenreactionen") the highest temperature is midway between the tip of the inner cone and the nearest point of the outer one.

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partial combustion, is indivisible. More air merely cools it, until finally it goes out. We thus pass from a Bunsen flame in which there are excess of coal-gas and two areas of combustion to a flame where there is excess of air and only one cone of combustion.

To use the apparatus for non-luminous flames from liquid hydrocarbons, all that is required is a current of air from a gas-holder, so arranged that any desired fraction can be sent through a "saturator." Such saturators as are used for the ether-oxygen lime-light serve excellently; but for ordinary purposes a wide glass tube, containing a roll of flannel soaked with the hydrocarbon, answers very well. The air, after passing through the saturator, rejoins the main current, and passes into the apparatus, where, by suitable regulation, a non-luminous flame can be obtained, and separated into two cones. The appearances presented are, in the case of liquid hydrocarbons, not quite the same as with those which are ordinarily gaseous. As a rule, with the vapours of liquid hydrocarbons a considerable degree of luminosity is maintained until the moment of descent of the inner cone, whereupon both cones become non-luminous. Besides this, the inner cone presents a peculiar appearance. It is divided by dark lines into several (usually five or six) petal-like segments, which often revolve with great rapidity round a vertical axis. Air charged with benzene vapour affords an example of this class of flames, and with it also two more points of special interest may be observed. If, after the two non-luminous cones have been separated, the supply of benzene-vapour be increased, a luminous tip appears in the inner cone, and on further increasing the benzene this tip extends as a vertical streak of separated carbon. It is luminous for some distance above the inner cone, then cools down, and only becomes incandescent again on passing through the tip of the upper cone. If the benzene supply be diminished, the luminous streak disappears, the upper cone becomes smaller and smaller, and finally disappears altogether. Meanwhile, the inner cone has become smaller, and more vividly blue and hotter, and now the whole combustion is taking place in this single cone of flame. If more benzene be cut off, the proportion of air becomes excessive, the flame cools, loses brilliance, and slightly enlarges. Finally, a further diminution of benzene caused the flame to rise from the inner tube, slowly pass upwards, and disappear. These appearances are shown in Plate I, which is from photographs, and represents the gradual transition without even momentary extinction from a flame containing excess of hydrocarbon to one containing excess of air.

Analytical Methods.—The first analyses, made with a view to determining approximately the constituents of gases coming from the inner cone of flame, were done with Hempel's apparatus. The appa-

ratus subsequently employed was of two kinds, one for gravimetric determinations specially devised, and the other the gas analysis apparatus invented by Dittmar and Lennox, and constructed for us by Messrs. Baird and Tatlock. We do not propose at present to describe either apparatus. A description of the Dittmar-Lennox apparatus in its present form has not yet been published, but the essential features are described by Professor Dittmar, in the new edition of *Watts's Dictionary of Chemistry*, 1, 245. We have to express our indebtedness to Mr. Lennox, for valuable assistance in connection with the use of the apparatus, which we have found exceedingly handy. The volumetric process is of course much the shorter and easier, but the quantity of gas used is small, and we were driven to use a gravimetric method, in order to have a means of directly determining water-vapour, and, by operating on large quantities of gas, to have a control for the volumetric process more usually employed.

It is unnecessary here to enter into details of the methods of carrying out the analysis and calculating results. We have made many dozens of analyses, and, knowing to what extent the methods are trustworthy, shall be careful to give only such results as we believe to be quite reliable for the purposes for which they are used. We take this course chiefly because it now appears to us necessary to devise still more accurate methods for dealing with the problems raised by our experiments, and we hope eventually to repeat all our analyses with a new apparatus. The methods used break down when small quantities of hydrocarbons have to be determined.

Experiments with Hydrocarbons.

We proceed to give a list of the hydrocarbons used, adding remarks as to any special features noticed.

Ethylene.—The two cones may be separated before the lower one is free from separated carbon, or they may be made non-luminous. In the former case some acetylene comes from the inner cone.

Methane.—Both cones non-luminous.

Pentane.—Inner cone channelled by dark spaces, and open at the tip.

Heptane.—Same as pentane.

Benzene.—Already described. The inner tube must have a smaller diameter than in the other cases, otherwise it is impossible to arrest the inner cone. When the inner cone has a luminous tip, it gives off acetylene.

Coal-gas.—Already described. Tubes of various diameters were used.

The following numbers are extracted from our experimental results, and in most cases were repeatedly verified.

Gas.	C ₂ H ₄ .	C ₂ H ₄ .	CH ₄ .	C ₆ H ₁₂ .	C ₇ H ₁₆ .	C ₆ H ₆ .	Coal gas.		
Diameter of outer tube in mm. . . .	29	29	29	20	20	19	29	19·5	28
Diameter of inner tube in mm. . . .	20	20	20	13	13	8	20	12	8
Gravimetric (G) or volumetric (V)	G	V	V	V	V	V	G	V	V
CO ₂	3·8	3·6	6·8	7·0	6·5	13·1	3·8	4·2	4·8
H ₂ O	9·5	9·5	17·6	13·1	12·3	7·7	14·9	16·0	15·9
CO	15·3	15·6	4·5	7·9	9·5	5·0	10·2	8·8	7·1
Hydrocarbon	0·8	1·3	*	*	*	0·6	*	*	*
H ₂	9·5	9·4	3·9	5·4	5·8	0·64	10·9	9·3	7·7
N ₂	61·1	60·6	67·2	66·2	65·6	73·1	60·3	62·0	64·4

From the above analyses it is evident that the gases in all cases were mainly carbon dioxide, water-vapour, carbon monoxide, and hydrogen, together with the nitrogen accompanying the air supply. In some cases a small quantity of "hydrocarbons" is set down. This is the most unsatisfactory feature in the analyses, for the uncertainty as to the nature and quantity of these hydrocarbons affects the whole analysis. It has been necessary in calculating the results to make some arbitrary assumption as to the nature of the hydrocarbons, and on this account, as well as from the fact that the substances employed were not in all cases pure, the analyses must only be considered as preliminary. It will be observed that variation in the diameter of the tubes has a considerable effect on the products of partial combustion. Diminution of diameter of the inner tube necessitates the employment of more air, and so increases the proportion of carbon dioxide and water formed. In no case was free oxygen found in the gases.

In the case of coal-gas, the mixture burning at the inner tube consisted of about 1 vol. of coal-gas to 4·8 vols. of air, and so contained about twice the normal amount of air for a Bunsen flame. In the case of benzene, the gas consisted of 1 vol. of benzene vapour to about 30 of air.

* Quantity of hydrocarbons too small to estimate.

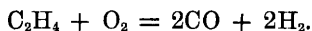
General Considerations on the Results obtained with Hydrocarbons.

From the foregoing results it is clear that when a hydrocarbon is burnt with air in sufficient quantity, the flame consists of two distinct hollow cones, the inner one tending to propagate itself downwards, the outer one tending in the opposite direction. This is indeed no new discovery, though we find that many chemists have been in the habit of regarding the Bunsen flame rather as a single mass of glowing gas with an inner and outer surface than as two cones of flame. Blochmann in his well-known paper (*Ann.*, **168**, 295) states explicitly that the flame has the two-coned structure. In an ordinary Bunsen flame these cones approximate to one another very closely, and only when the air supply is increased is their separate existence evident. The thickness of the walls of the cones is very slight, and this is particularly the case with the inner cone. It is bounded on the lower side by a ready-made explosive mixture, so that the chemical action is very intense and local. Outward from it proceed gases which have to make their own explosive mixture by diffusing with the outside air until the necessary oxygen is obtained. The large size, greater thickness, want of sharpness, and lower temperature of the outer flame are thus explained. The theory of the separation of these cones has already been given.

Perhaps the most remarkable fact apparent from our analyses is that the main chemical change occurring in the inner cone consists in the combustion of the hydrocarbons to form carbon monoxide and water with smaller quantities of carbon dioxide and hydrogen. But here again we find on referring to Blochmann's paper that he infers that this kind of change takes place in the ordinary Bunsen flame. The importance of his observation has no doubt been overlooked on account of the fact that he used coal-gas, which, in the unburned state, contains about half its volume of hydrogen. It is, at any rate, satisfactory to have proved the existence of such a change with definite hydrocarbons and in a perfectly direct manner.

At the time when we obtained these results we were not aware of what we have since found to be some well-established facts concerning the combustion of hydrocarbons with oxygen insufficient in amount for their complete oxidation to carbon dioxide and water. But a short time subsequently, after we had discussed the subject with Professor H. B. Dixon, it happened independently to him and to ourselves to discover that the incomplete oxidation of methane and ethylene had been studied at the beginning of the century. Dalton states that ethylene exploded with its own volume of oxygen gives carbonic oxide and hydrogen, and that marsh gas, under

similar conditions, gives equal volumes of steam, carbonic oxide, and hydrogen.



The incomplete combustion of these hydrocarbons was studied again in 1861 by Kersten (*J. pr. Chem.*, **84**, 310) who, in the main, substantiates Dalton's results although they were evidently unknown to him. Without reference either to Dalton or Kersten, the subject was again taken up in 1874 by E. von Meyer and similar results obtained, and at the same time, experiments of the same kind were made independently by Thomas.*

We do not think the explanation of the facts observed is difficult to find. That carbon on oxidation, even with excess of oxygen, burns first to carbon monoxide, is highly probable from the experiments of H. B. Baker (*Proc. Roy. Soc.*, 1889, **45**, 1), but that carbon should burn more readily than hydrogen, is not in accordance with a widely prevailing, though scarcely justifiable belief. Without desiring to raise any confusion between questions of affinity and of energy, we may be allowed to draw attention to the thermochemical aspect of the question.

The calculated heat of combustion of solid carbon to carbon monoxide is only 29,000 calories, but the thermal effect is here diminished by the amount of heat necessary for the gasification of solid charcoal, and accordingly we find that the addition of a second atom of oxygen (that is, the conversion of CO into CO₂) gives a much greater heat evolution, viz. 67,960 calories.

Attempts have been made† to calculate the heat of combustion of gaseous carbon to carbon dioxide, but objection has been taken to them‡ on the ground that they virtually assume the heat of combination of the first and second atoms of oxygen to be equal. But in any case it is agreed that the combination of the first atom of oxygen

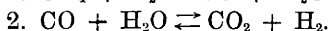
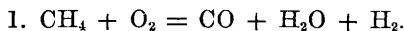
* We are indebted to Professor Thorpe for drawing our attention to the work of Thomas, an account of which appears in *Iron*, 1875, and in an appendix to "Coal-mine Gases and Ventilation," by J. W. Thomas, Longmans and Co., 1878. On this point Professor Dixon writes to us: "In the spring of last year I determined the rate of the explosion-wave in a mixture of ethylene with its own volume of oxygen. I found *detonation* took place, and that the oxygen was entirely taken by the carbon setting hydrogen free, in accordance with Blochmann's equation and with E. von Meyer's results, which I doubted. After making these experiments, I happened to come across Dalton's work in the second part of his *New System*. I did not know that Kersten had done it; I have to thank you for calling my attention to his work."

† See especially Thomsen, *Thermochem-Untersuch.* Band IV.

‡ Armstrong, *Phil. Mag.* [5], **23**, Feb. 1887.

with a carbon atom produces at least as much heat as that of the second atom, viz., 67,960 calories, and this is more heat than is evolved in the combustion of hydrogen to gaseous water (57,900 calories). The last number is, however, the heat of combination of a *molecule* of hydrogen, and to it must be added the heat necessary for the separation of this molecule into atoms. No reliable estimate of this value has ever been made.

We may suppose that in our experiments, when the hydrocarbon first burns in the inner cone, there is a distribution of the limited supply of oxygen between the carbon and hydrogen, such, that either carbon monoxide and water or carbon monoxide, water, and hydrogen are first formed. The two gases carbon monoxide and water, cannot exist at the temperature of the flame without a second interaction immediately taking place, whereby the former is oxidised by the latter with the production of the carbon dioxide and hydrogen. This, however, is a reversible change, and the decomposition is not complete. There thus remain four gases, carbon monoxide, hydrogen, carbon dioxide, and water, together with the nitrogen which accompanied the oxygen in the air-supply. The changes then would be as follows with methane:—



The conditions of equilibrium for this system of gases have been worked out by Dixon in his well-known memoir (*Phil. Trans.*, 1884, 618). It was, therefore, a matter of great interest to us to see to what extent we got a constant ratio of products, and how our ratios agreed with Dixon's constant. This, however, is one of the questions into which we do not feel at present prepared to enter. We will only remark that whilst Dixon gives the normal condition of equilibrium as follows $\frac{\text{CO} \times \text{H}_2\text{O}}{\text{CO}_2 \times \text{H}_2} = 4.0$, we obtain from our most reliable analyses numbers not greatly differing from 4. More accurate analysis of the gases, the influence of differing diameters of the tubes, rates of efflux, and quantities of diluent gases are questions on which we are at present engaged, and demand careful study before we can put forward any conclusions on the question of equilibrium, which is perhaps the most interesting and important aspect of our work.

With regard to the relation of our results to those obtained by Blochmann in his experiments on the normal Bunsen flame, it has been already pointed out that there is substantial agreement on the main points. But, as in our experiments, the gases were burning with a much greater supply of air, the quantity of hydrocarbons pass-

ing the first area of combustion was in many cases practically *nil*; whereas in Blochmann's experiments as much as 8·7 per cent. of hydrocarbons was found in the interconal space at a height of 5 cm. above the burner. We hope eventually to repeat Blochmann's experiments, using a definite hydrocarbon instead of coal-gas.

It seems possible by means of our apparatus to gain precise information as to the mode in which ethylene and other hydrocarbons break up when burning with luminous flames. It has already been stated, that it is possible to separate the cones of the ethylene-air flame before they have become non-luminous, that is, while carbon is being separated in the flame, and it is obvious that by an accurate analysis of the gases under these circumstances it should be possible to determine whether the carbon is being separated by the simple decomposition of the ethylene into its elements, by its resolution into carbon and methane, by the preferential combustion of the hydrogen, or by some other decomposition. That the process is complex is probable from the fact that we have found acetylene in the interconal gases. We intend to try to repeat Landolt's experiments (Pogg, *Annalen*, 99, 389) on the composition of gases from luminous flames, using ethylene instead of the complex coal-gas which he employed, but we are not very hopeful of gaining much information by this method.

Experiments with other Gases.

We have made a number of experiments with flames from substances other than hydrocarbons, and by supplying the mixed gas or vapour and air to the separating apparatus have "divided" the flames produced from decomposed ammonia (that is, $N_2 + 3H_2$), cyanogen, hydrogen sulphide, and carbon bisulphide.

With the mixture of hydrogen and nitrogen, obtained by passing ammonia through a hot tube, the phenomena is seen at its simplest, for here, in the first cone, the whole of the oxygen combines with hydrogen to form steam, which, with the nitrogen and excess of hydrogen, passes to the top of the outer tube, where this hydrogen burns with the outside air in a second flame.

With cyanogen* the phenomena are the most beautiful we have met with in the course of our experiments. The cyanogen, burning without added air, gives a flame with a rose-coloured central cone, and an outer cone shading from dark-blue to greenish-grey. As air is allowed to enter with the cyanogen, the margin of the inner cone assumes a deep, cherry-red tint, and it eventually descends to

* As we had not a convenient apparatus for storing cyanogen, Professor Dixon very kindly allowed us to make the experiment in his laboratory at Manchester.

the inner tube. The outer cone, now of a blue-grey colour, remains on the outer tube. If more air is supplied, the upper cone becomes imperfect, being gathered in at the base and not in contact with the glass, whilst the inner cone grows greyer. Eventually the upper flame altogether disappears, the lower one becoming bluish-grey. A sample of gas from the interconal space, withdrawn when the two separated cones were perfect, was found, on analysis, to contain carbon monoxide and dioxide, almost exactly in the proportion of 2 vols. to 1. No cyanogen could be detected by smell or analysis.

The combustion of cyanogen in a eudiometer with quantities of oxygen insufficient to convert the carbon wholly into carbon dioxide, was investigated by Bunsen (*Gasometrische Methode*, 2nd edition, p. 340). In two different experiments, he found the ratios of CO to CO₂ 1 vol. to 2 and 2 vols. to 5.

In our experiments we have been able to use a much smaller proportion of oxygen than Bunsen found possible, and the results show, as we should expect, that the production of CO is relatively much greater.

The sulphuretted hydrogen flame, when produced in our apparatus, is easily divided into two cones. We have not yet made a quantitative analysis of the gases from the interconal space, but most of the sulphur appears to pass the first cone without undergoing combustion.

The flame from carbon bisulphide vapour can be divided in the same way as is adopted for liquid hydrocarbons, but we have not yet made a quantitative study of the process.

There is still much to be done with the apparatus described in this paper. We have already indicated some of the points that have to be worked out, and we conclude by briefly summarising them.

1. The influence of differences in the diameter of the tubes, and rates of efflux of the gases on the fractional combustion.

2. The exact analysis of the interconal gases in the case of hydrocarbons and of mixtures of CO and H₂, in order to ascertain if, and in what way, the coefficient $\frac{\text{CO} \times \text{H}_2\text{O}}{\text{CO}_2 \times \text{H}_2} = 4$ varies with the composition of the gases.

3. The analysis of the interconal gas from an ethylene flame whilst carbon is being liberated, so as to determine how the hydrocarbon breaks up.

4. The further study of the cyanogen flame.

5. To determine the partition of oxygen in the inner cone between carbon and hydrogen, hydrogen and sulphur, carbon and sulphur, and so obtain information of the relative affinities of these elements for oxygen.
