II. *The Bakerian Lecture. On the composition and analysis of the inflammable gaseous compounds resulting from the destructive distillation of coal and oil, with some remarks on their relative heating and illuminating powers.* By WILLIAM THOMAS BRANDE, *Esq. Sec. R. S. Prof. Chem. R. I.*

Read November 18, 1819.

THE experiments detailed in the following pages, were originally undertaken with a view of ascertaining the relative fitness of the gases obtained by the decomposition of coal and oil for the purposes of illumination, and of elucidating some apparent anomalies in their economical applications. Merely as such, however, I should not have deemed them of sufficient novelty or importance to form the subject of the Bakerian Lecture; but during the progress of the inquiry, some new views relative to the constitution of these gaseous mixtures, suggested themselves, and some properties of terrestrial radiant matter became apparent, which I trust will be thought worthy the attention of this Society.

SECTION I.

On the inflammable gases afforded by the destructive distillation of pit coal and of oil.

THE gases used in the following experiments, except where it is otherwise expressly stated, were those employed for the common purposes of illumination; the coal gas being that supplied from the Company's works in Westminster, and the oil gas furnished by the decomposition of common whale oil, in an apparatus erected for that purpose by Messrs. TAYLORS and MARTINEAU, at Apothecaries' Hall.* These gases have been submitted to analysis by different chemists of eminence; and we are more especially indebted to Dr. HENRY for a series of valuable researches respecting their production and composition.† It is therefore with considerable diffidence that I venture to propose views relating to them in many respects different from those of my predecessors in this important branch of chemical inquiry.

It is generally admitted, that there are two definite compounds of carbon and hydrogen; the one, usually termed *olefiant gas*, consisting of *one* proportional of carbon and *one* of hydrogen; and the other called *light hydrocarburet*, composed of *one* proportional of carbon and *two* of hydrogen: the former of these gases appears to have been discovered in 1796, by the associated Dutch chemists, Messrs. BONDT, DIEMAN, VAN TROOSTWICK, and LAWERENBOURG,‡ and the other first examined by Mr. DALTON.§ Assuming hydrogen as 1, the specific gravity of olefiant gas is 13,4; and it contains 1 proportional of carbon $= 5{,}7 + 1$ proportional of hydrogen $= 1$. Light hydrocarburet has generally been

* A description and plate of this apparatus is given in the Quarterly Journal of Sciences, &c. Vol VIII. p. 120.

† NICHOLSON's Journal, Vol. XI. p. 65. Philos. Trans. 1808. Manchester Memoirs, Vol. III. New Series.

‡ Journal de Physique, XIV. § New System of Chemical Philosophy.

considered as consisting of 1 proportional of carbon = 5,7 + 2 proportionals of hydrogen = 2, and its specific gravity has been stated as 7,7 compared with hydrogen; or as 57365, assuming atmospheric air as 1.

My first object in the examination of coal gas was to ascertain its specific gravity; and I was surprised to find the first that I examined so low as ,4430. There was some variation in different specimens; and the specific gravity of that prepared in the laboratory of the Royal Institution, and purified in the usual way by condensation in cold vessels, and passing through lime water, was as high as ,4940, which is the heaviest that I have yet met with.

Having been led to consider coal gas as consisting essentially of the two varieties of carburetted hydrogen, I imagined that the specific gravity of the light hydrocarburet must have been estimated too high; I therefore prepared light hydrocarburet from acetate of potash, and having separated its carbonic acid by lime, found its specific gravity ,687; the specific gravity of the gas from stagnant water, according to Mr. DALTON,* is ,600, and that from moistened charcoal when purified is ,480.† It became evident, therefore, that coal gas could not consist principally of the two hydrocarburets; nor could the presence of carbonic oxide be suspected, its specific gravity being ,9834. Hence it occurred to me, that the only mode of explaining these apparent anomalies, was to consider coal gas as a mixture of olefiant and hydrogen gases; and the following experiments were undertaken with a view to determine this point.

* New System of Chemical Philosophy. † HENRY's Elements, p. 320.

1. One hundred volumes of coal gas were detonated by the electric spark over mercury, with 200 of oxygen; the carbonic acid was absorbed by liquid potassa, and 36 volumes of pure oxygen remained in the tube. Whence it appears that 100 volumes of the coal gas under examination required for its perfect combustion 164 parts of oxygen; consequently, as 100 parts of olefiant gas require 300 of oxygen, and 100 of hydrogen 50, for their respective combustion, it might be concluded from the above experiments, supposing no foreign gases present, that the 100 of coal gas consisted of about 55 parts of hydrogen and 48 of olefiant gas; a mixture, of which 100 cubical inches would weigh nearly 15 grains, and which closely corresponds with the specific gravity of the coal gas.

2. One hundred measures of coal gas were introduced into a small bent glass tube containing a little sulphur, and inverted in mercury; a red heat was applied until the inclosed gas underwent no further dilatation; and on examining its volume when cold, it was found to occupy 140 measures. If we consider the increase of bulk as resulting from the decomposition of olefiant gas, this experiment gives the composition of coal gas 60 hydrogen and 40 olefiant by volume.

3. One hundred measures of coal gas were introduced into a mercurial gasometer, connected with a second gasometer by means of a platinum tube, in the manner described by Messrs. ALLEN and PEPYS, in their Essay on the Combustion of Carbon.* Some small quartz crystals previously heated red hot were introduced into the platinum tube, which was heated bright red; the gas was then passed through it from

* Phil. Trans. 1807.

one gasometer to the other for about a quarter of an hour. The apparatus having cooled, the gas was found to have sustained an increase of volume = 40 parts; it burned with the pale flame of hydrogen; and when detonated over mercury required scarcely more than half its volume of oxygen, and afforded a very minute portion of carbonic acid. The interior of the platinum tube was lined with charcoal, the crystals were covered with it, and some had assumed a beautiful brown tint.

4. The conclusions drawn from the last experiment are founded upon the supposition, that olefiant gas is decomposed by the simple operation of a high temperature, and that one volume is resolved into two volumes of hydrogen, losing at the same time its carbon. The importance of this fact, as connected with these researches, induced me to repeat with every requisite precaution, the beautiful experiment of M. BERTHOLLET, which consists in decomposing this gas by passing it repeatedly through a red hot earthen tube; instead of which, however, I employed a tube of platinum, arranged as in the last experiment, increasing the heated surface by the introduction of quartz crystals. One hundred measures of olefiant gas,* obtained by distilling alcohol with sulphuric acid, were passed and repassed through the tube heated to high redness, until they ceased to dilate: when the apparatus was cool, the volume of gas was almost exactly doubled; there was a copious deposition of charcoal in the part of the tube that had been ignited, and the evolved hydrogen was so

* This gas was washed with solution of potassa to separate a little carbonic acid, and was then ascertained to be pure by the action of chlorine, with the precautions afterwards described.

free from carbon, that when detonated with its volume of oxygen, half a volume of the latter remained, which scarcely rendered lime water turbid, and underwent no perceptible diminution by exposure to liquid potassa.

It may be supposed, that in consequence of the dilution of the last portions of olefiant by the hydrogen evolved, the perfect decomposition of the gas is a matter of difficulty, and a trace of carbon will, I believe, always remain in the hydrogen evolved, since the decomposition is progressive. I cannot, however, on this account see reason to believe, with M. BERTHOLLET,* that carbon and hydrogen are capable of forming several definite compounds; the data are, on the contrary, such as to warrant an opposite conclusion.

In making this experiment in the manner just described, and more especially when the tube is only dull red, the first portions of gas that reach the receiving gasometer, are obscured by a considerable quantity of vapour, which, however, afterwards disappeared. To examine more particularly the cause of this phenomenon, I passed some pure olefiant gas, very slowly, through a red hot glass tube, about two feet in length, and containing in the heated part some pure and well burned charcoal: the gas was collected in a cold receiver, the sides of which became lined with a brown viscid substance of an agreeably fragrant odour, perfectly soluble in alcohol, and precipitated from this solution by water, which rendered it turbid, and of a whitish green hue. This peculiar resinous matter appears to be a compound of hydrogen and carbon; its vapour is perfectly decomposed by passing it

* THENARD, Traité de Chimie, Tom. I. p. 293.

through a highly heated platinum tube, hydrogen being evolved and carbon deposited.

5. Mr. FARADAY, whose accuracy as an operator is not inferior to his assiduity as my Assistant in the Laboratory of the Royal Institution, has shown in a paper published in the Quarterly Journal of Science, that the supposed distinction between olefiant and light hydrocarburet, by means of the action of chlorine, has no foundation; and that at common temperature, all varieties of carburetted hydrogen are condensed by, and combine with, chlorine.

To ascertain how far the action of chlorine could be depended upon as a means of analyzing mixtures of olefiant and hydrogen gases, I mixed equal volumes of chlorine and hydrogen, over water at the temperature of 55°, in a tube of half an inch diameter, and exposed to ordinary daylight, but carefully excluded from direct sunshine. After twenty-four hours, the whole of the chlorine had been absorbed by the water, and the original volume of hydrogen remained unaltered.

One volume of hydrogen mixed with one of olefiant gas and two of chlorine, was reduced under the same circumstances to very little more than one volume, the whole of the olefiant having been absorbed.

In these cases it is convenient to use considerable excess of chlorine, and in this way the purity of olefiant gas may be ascertained; it will be found, even when obtained with every caution, to afford a small residue of hydrogen; but as this is sometimes as little as one per cent, it may, generally speaking, be disregarded.

6. The analysis of a mixture of hydrogen with carburetted

hydrogen, carbonic oxide, and carbonic acid, presents peculiar difficulties in the ordinary mode of proceeding; and as it often requires to be performed in investigations relating to the gases used for illumination, it became an object to facilitate the process, for which I have used the following plan.

A hundred measures of the gas are introduced into a graduated tube, and the carbonic acid absorbed by a solution of potassa; the remaining gas is then transferred to thrice its volume of chlorine of known purity, standing over water in a tube of about half an inch diameter, and exposed to daylight, but carefully excluded from the direct solar rays; after twenty-four hours the carburetted hydrogen and the excess of chlorine will have been absorbed, and the remaining gas, consisting of carbonic oxide and hydrogen, may be analysed by detonation with oxygen in excess; the measure of carbonic acid formed being the equivalent of that of the original carbonic oxide.

This proceeding depends upon the non-formation of chloro-carbonic acid in a mixture of carbonic oxide and chlorine in the contact of water, and out of the direct agency of the solar rays. Such mixture I have kept several days, occasionally renewing the chlorine as it became absorbed by the water, and have not observed any diminution in the bulk of the carbonic oxide. In all these cases it is necessary to ascertain the purity of the chlorine by its absorption by water, and to be aware of the evolution of common air from water during that process.

7. I repeated many of the above experiments, substituting for coal gas a mixture of six volumes of hydrogen with five of olefiant gas. The specific gravity of this mixture was,

,4700; one hundred cubical inches weighing 14,2 grains. The flame with which this mixture burned was of the same colour and intensity as that of common coal gas; its dilatation by heat was similar, and it underwent an analogous increase of bulk when heated with sulphur.

The readiness with which carburetted hydrogen is decomposed, when passed through red hot tubes, appears to me to offer a solid objection to a mode of purifying coal gas, which has been proposed by Mr. G. H. PALMER,* since it would deposit carbon, and consequently sustain great loss in illuminating power. The object in view was probably to get rid of the sulphuretted hydrogen; but neither is this so to be attained. In examining coal gas, I have often been struck with the formation of sulphurous acid during its combustion; though when passed through solution of acetate of lead, it occasioned no blackening, a circumstance which led me to suspect the presence of some other sulphureous compound; and I have often thought, in passing the open gas pipes in the streets, that I perceived the smell of sulphuret of carbon. When sulphurous acid or sulphuretted hydrogen are passed with carburetted hydrogen through a red hot tube, a portion of carburet of sulphur is always formed, and the vapour of that highly volatile compound may well exist in the gas employed for illumination, which is always hurried through the condensers and gasometer.

8. Most of the above experiments were now repeated upon the gas obtained by the decomposition of whale oil; its specific gravity was ,7690; so that 100 cubical inches weighed rather more than 23 grains. Deducing the compo-

* PECKSTON, on the Theory and Practice of Gas-lighting, p. 213.

sition of this gas, considered as a mixture of hydrogen and olefiant, from its specific gravity, we should conclude that it is composed of 1 volume of hydrogen and 3 of olefiant, upon the presumption that 100 cubical inches of hydrogen weigh 2,25 grains, and 100 of olefiant 30,15.

Such a mixture, when submitted to the action of heat, of sulphur, and of chlorine, and when detonated with oxygen, afforded results similar to those obtained by experiments upon the original oil gas, and it burned with the same degree of brilliancy.

9. I have also submitted to similar experiments the inflammable gases obtained by the decomposition of acetate of potash, of alcohol, and ether, and by passing water over red hot charcoal. All these contain a considerable portion of carbonic acid, which, when abstracted by potassa, leaves a mixture of carburetted hydrogen, hydrogen, and carbonic oxide, in proportions liable to much variation, according to the materials employed, and to the circumstances under which their decomposition has been effected. The specific gravity of these products is of course liable to corresponding variations.

10. The inference which, I think, may be drawn from the preceding experiments and observations, is, that there exists no definite compound of carbon and hydrogen, except that usually called *olefiant gas;* that the various inflammable compounds employed for the purpose of illumination, and produced by the destructive distillation of coal, oil, &c. consist essentially of a mixture of olefiant gas and hydrogen; that the gas procured from acetate of potash and from moist charcoal contains the same elements, with carbonic oxide and

carbonic acid; and that no other definite compound of carbon and hydrogen can be recognised in them, except olefiant gas.

SECTION II.

Comparative experiments on the illuminating and heating powers of olefiant, coal, and oil gases, and on some general properties of radiant matter.

1. In the following experiments I employed a gasometer with counterpoise weights acting over regulating pullies, and capable of containing about 5000 cubical inches, or about 2,89 cubical feet: the different jets were attached to it in the usual way, and the pressure was measured by the difference in the level of the water within and without the bell, to which was attached an accurately graduated scale sliding through the frame of support.

2. Having filled this gasometer with pure olefiant gas, it was allowed to issue from a brass jet having a single perforation of $\frac{1}{60}$ of an inch diameter, under a pressure of a half inch column of water; it was then inflamed, and regulated by means of a stopcock, so as to produce a light equal to that of a wax candle burning with full brilliancy; the relative intensity of the light of these flames was ascertained by a comparison of shadows. Under these circumstances, the consumption of gas was found =640 cubical inches per hour, or 0,37 cubical feet. When the same burner was used with oil gas, it consumed 800 cubical inches per hour, or =0,47 cubical feet.

3. I now employed an Argand burner, with a cylindrical glass, constructed in the usual way, with 12 holes each of the

same dimensions as that of the single jet, and forming a circle 0,7 inch diameter. The pressure being 0,5 inch, the flame was so regulated as to burn with its full intensity without producing smoke, and its light being measured by a comparison of shadows, it was found equal to ten wax candles. The consumption of gas amounted to 2600 cubical inches, or about a cubical foot and a half per hour.

If the result of this experiment be compared with the above, in which a single jet was used, it will appear, that the proportion of light from a given quantity of gas is increased in a very high ratio by employing many flames near each other, the consumption of the single jet giving a light of one candle, being $=640$ cubical inches, whereas the Argand burner gave a light of ten candles, with a consumption not of 640×10 cubical inches, but of 2600 cubical inches. It will be remembered, that in the latter, the combustion is perfected by a central current of air, rendered more rapid by the glass tube which surrounds the flame. Count Rumford showed some time ago, " that the quantity of light emitted by a given portion of inflammable matter in combustion, is proportional in some high ratio to the elevation of temperature, and that a lamp having many wicks very near each other, so as to communicate heat, burns with infinitely more brilliancy than the Argand's lamps in common use."* The construction of the gas Argand burner is particularly calculated to produce an effect of this kind; and to such a cause the great increase of light relative to the consumption of gas may probably be attributed.†

* Davy's Elements of Chemical Philosophy, p. 224.

† In the annexed drawing (Plate III.) is represented an Argand burner for oil

4. The gasometer being filled with oil gas, an Argand burner, giving the light of eight wax candles, was found to consume 3900 cubical inches per hour; and the same intensity of light was produced by the same quantity of artificial oil gas; that is, of a mixture of three parts of olefiant and one of hydrogen.

5. The apertures of burners for coal gas require to be considerably larger than those for olefiant or oil gas. In the burner employed in the following experiments, each hole was $\frac{1}{30}$ inch diameter, and the circle upon the circumference of which they were placed, was 0,9 inch diameter. The light of the flame was found equal to five wax candles only, and the consumption of gas per hour amounted to 6560 cubical inches.

With a mixture of six parts by measure of hydrogen with five of olefiant gas, the light of the flame was somewhat more intense; and the quantity of gas consumed by the same burner, so adjusted as not to smoke, was 6000 cubical inches.

6. It appears from the above data, that to produce the light of ten wax candles for one hour, there will be required,

2600 cubical inches of olefiant gas.
4875 - - - oil gas.
13120 - - - coal gas;

gas, upon what I believe to be the most economical construction. The bevilling of the perforated edge contributes greatly to the perfection of the light, as shown in the section, Fig. 1. The diameter of the circle of holes is 0,7 inch, and the holes should not be more than $\frac{1}{60}$ of an inch in diameter. Consuming at the highest average 4000 cubical inches per hour, it gives the light of between eight and nine wax candles of four to the pound.

Fig. 3. is a sketch of what is technically termed a *rose burner*; it has six holes of the same dimensions as those of the Argand, and when so regulated as to produce a light equal to that of six wax candles, its greatest average consumption of gas amounts to 4800 cubical inches per hour.

and that the quantity of oxygen consumed

by the olefiant gas will be = 7800 cubical inches.
by the oil gas - = 11578.
by the coal gas - = 21516.

Olefiant gas cannot of course be employed for any economical purposes, and is only here adverted to for the sake of comparison. The relation of the quantity of oil gas to that of coal gas, furnishes a datum that may be practically useful, especially as indicating the relative sizes of gasometers required for the supply of establishments. It may, I think, be stated with sufficient accuracy for practical purposes, that a gasometer containing 1000 cubical feet of oil gas, is adequate to furnish the same quantity of light as one of 3000 cubical feet of coal gas, provided due attention be paid to the construction of the burners, and to the distribution of the lights.

7. For the ordinary purposes of illumination by oil gas, I consider ten hole Argand burners, each consuming about a cubical foot and a half per hour, and giving the light of seven wax candles, or nearly two oil Argands, as the most economical and generally useful. Single jet burners, or those in which the flames do not coalesce, consume, as has been above shown, a very much larger quantity of gas for the production of an equal quantity of light; and for the same reason, Argand burners, in which the flames do not coalesce, consume more gas for an equal production of light, than those in which the apertures are more numerous, but sufficiently near each other to allow of the union of the separate flames.

8. To ascertain the relative heating powers of the flames of olefiant, oil, and coal gases, I employed the twelve hole Argand burners mentioned above, and placed over each, as near to the lamp glass as was consistent with a clear flame, a

clean copper boiler, 2,5 inches deep and 5 inches diameter, slightly concave at bottom, capable of holding rather more than a quart of water, with an immersed thermometer, and a small vent for steam. It contained two pounds of distilled water, which was raised to the boiling point in similar times, namely, 20′ by each of the flames; so that it would appear, that to raise a quart of water from 50° to 212,° at 30 inches barometrical pressure, requires

870	cubical inches of olefiant gas,		
1300	-	-	oil gas,
2190	-	-	coal gas.

From this experiment it may be inferred, that the air of a room equally lighted by oil and coal gas, will be much less heated by the former than the latter; but that the actual heating power of the flames is in the direct ratio of the quantity of olefiant gas.

9. Having occasion in some of the foregoing experiments to produce light of great brilliancy by the combustion of olefiant gas, and finding it very difficult to measure its intensity by a comparison of shadows, in the manner pointed out by Count Rumford, I endeavoured to avail myself of Mr. Leslie's photometer; for this purpose I concentrated the light by a plano-convex lens, and placed the blackened ball of the instrument in the focus. I found the effect, however, so great, as to lead me to believe that I had obtained a focus of considerable heating power, and on substituting a delicate mercurial thermometer, it rose 4°,5 in 5′. In the focus thus obtained from the light of a large Argand burner supplied with olefiant gas, the elevation of temperature was very sen-

sible to the hand, and in depressing and elevating the flame by means of a regulating stopcock, corresponding effects were produced upon the thermometer: the lens itself, which was a thick one, did not become heated.

These experiments coincide in result with those of Dr. MAYCOCK, and of M. DELAROCHE,* and show that the calorific rays emanating from common combustibles, are capable of passing through transparent media like those of the sun.

10. There are certain substances, the chemical relations of which are singularly affected by the influence of direct solar rays. Among these, the mixture of chlorine and hydrogen is most remarkable: if kept in common daylight, but out of direct sunshine, the gases do not act upon each other; but the moment the mixture is placed in the sunshine, the muriatic acid begins to be formed. I therefore hoped that this property might be applicable in certain photometrical experiments. I exposed a mixture of equal volumes of chlorine and hydrogen, in a tube inverted over water, capable of holding about four cubical inches, and blown into a thin bulb at its upper extremity, to the brilliant focus produced by a large olefiant gas flame; it was exposed for 15′, but underwent no other change than a slight increase of bulk, acting as an air thermometer.

11. It now occurred to me to try how far any effect would be produced by the more intense light of the Voltaic battery, and I placed the tube containing the mixed gases in a darkened room, within about an inch of the charcoal points connected with an apparatus of one hundred pairs of plates highly

* MURRAY's System of Chemistry, Vol. I. p. 336. 4th. Edition.

charged: upon making the contact, the effect of the light upon the mixed gases was very remarkable; fumes of muriatic vapour were instantly produced, the water rose in the tube in consequence of the production of muriatic acid, and in about five minutes the absorption was entire; but the most curious circumstance was, that in two instances an explosion of the gases took place the moment they felt the impulse of the electric light.

12. As I have in no case been able to produce an analogous effect by any other terrestrial light, however intense, I cannot but consider the phenomenon as dependent upon some peculiar property belonging to the rays of solar and electric light.

The lunar rays produce no effect upon mixed chlorine and hydrogen, nor upon chloride of silver; neither was the whiteness of the latter in the slightest degree impaired by the most powerful luminous focus that I could obtain from an olefiant gas flame.

13. In some experiments connected with the subjects of this communication, I have availed myself of a photometric thermometer, acting upon the principle of that described by Mr. Leslie, but infinitely more sensible; it is constructed nearly in the same way as the differential thermometer, but instead of containing air, the balls are filled with the vapour of ether, and the stem contains a column of that liquid; it thus forms a very delicate differential thermometer. To convert it into a photometer, the upper bulb is covered with a thin coating of Indian ink, and the lower one with silver or gold leaf; the whole instrument is then placed in a pellucid glass tube: when taken out of its case the influence of light

is perceived at the instant of exposure, by the falling of the liquid from the blackened to the metallic side; it is powerfully influenced by the flame of a candle at the distance of one foot, and proportionally by other luminous bodies.

Fig. 1.

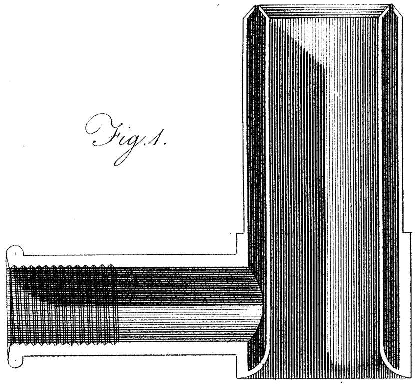

Fig. 2.

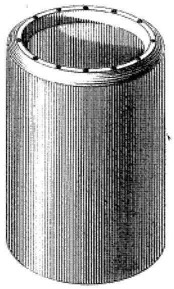

Fig. 3.