NATURE-STUDIES

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FLAME.

BY PROFESSOR F. R. EATON LOWE.

A BRILLIANT flame is the first object to fix the gaze of the young infant; and in manhood we still continue to feel a strange fascination under the influence of the same phenomenon. Even phosphorescence, unaccompanied as it is by flame, has an irresistible charm for us; while the vivid combustion of inflammable matter embodies a power and impetuosity which rivet the attention of the most stolid observer. We smile at the stupidity of the moth that singes its wings in the candle-flame; but there is within us a similar mysterious impulse that would impel us into the burning mass but for the consciousness of resulting injury, derived solely, as metaphysicians tell us, from knowledge gained by experience. Who is not struck with the splendor of a brilliantly lighted hall or theatre? Indeed, the beauty and luster imparted to large rooms by judicious lighting have no small share in the production of the vivacity felt by the audience generally. Turning to combustion on a large scale, with flames raging in uncontrollable fury, and material undergoing rapid destruction, there is probably no phenomenon in nature except, perhaps, the electric discharge, that impresses us with a stronger feeling of awe. A conflagration, from a bonfire to a building in flames, from a chimney on fire to a blast furnace belching forth its fiery tongues high into the air, is a fit emblem of ungovernable fury and relentless destruction. But it is more to our present purpose to regard flame as an instrument for good rather than evil. Most of the comforts and luxuries and even necessities of modern civilized life are due directly or indirectly to its agency; indeed, it would be difficult to name an art or manufacture which does not owe to flame its very birth. At home and abroad, in the house, the street, and the mart, we are surrounded by a multitude of substances which have been produced by the application of heat in one form or another. The spirit-lamp, the Bunsen burner, and the gas furnace, are the Alpha and Omega of the chemist's laboratory—the chief auxiliaries by whose magic power the multifarious compounds now become objects of commercial enterprise and sources of enormous wealth to the country, were originally prepared on a small scale. As a single example out of a thousand, take the manufacture of carbonate of soda from sea-salt more than 200,000 tons of which, of the value of two millions sterling, are annually made in the alkali works of Great Britain. The salt is first converted into sulphate of soda by the action of sulphuric acid; the sulphate of soda is then converted into carbonate of soda by being heated with chalk and carbon. This important substance was formerly manufactured from barilla; and the interesting chemical process now employed on so gigantic a scale was the result of an experiment with substances heated in an evaporating dish by means of a spirit-lamp. Armed with his Bunsen burner the young chemist can produce a multitude of results not recorded in his books; and the present rapid growth of applied science affords him every encouragement to persevere in researches which may result in discoveries of public utility.

All life, vegetable and animal, on the surface of the globe, is sustained by heat emanating from flames existing in the sun's photosphere or luminous envelope. These "red flames," as they are termed, are visible only during a total eclipse of the sun, and are of inconceivable magnitude, shooting with tumultuous fury to a distance of about 30,000 miles from its surface. Of the nature of these gigantic flames we shall have more to say anon; we prefer to begin our investigations at home, and lighting the humble and antiquated tallow candle, study the chemical reactions concerned in its combustion. Here we must say a word upon combustion generally. All the ordinary sources of illumination, as tallow, wax, oil, and coal-gas, are kept in a state of ignition by the oxygen of the air. If we place our lighted candle at the bottom of a wide-necked bottle, it will soon be extinguished from the want of its powerful supporter.

The flame of an ordinary lantern or lamp, where a chimney is employed, would not burn more than a few minutes if holes were not provided at the base for the ingress of air. But for the occasional application of the poker, the combustion of a common fire would be maintained with difficulty, or prematurely put an end to, for the oxygen of the air must find free access to the interior of the burning mass, or the chemical decompositions we are about to describe cannot take place. On the same principle the best way of extinguishing fire is to smother it; that is, to cover it closely with something that will effectually cut off the source of its existence. If the clothes of some unfortunate friend should happen to catch fire, the best course to follow is to throw him down and envelop him in a rug, blanket, or anything of a similar kind within reach, when the flames will be immediaetly extinguished. To run about in search of water or assistance in these cases is simply to give time to the flames to reach a vital part of the body. But to return to our tallow candle, which is burning as brightly as can reasonably be expected from a consideration of the very small sum paid for it. If any prejudice against this humble luminary should exist in the mind of the reader, a glossy wax, paraffin or composite candle will do just as well. With the flame before us two questions arise with respect to it. Firstly, what is it that burns,—the wick, the tallow, or both? Secondly, What is the composition of the tallow? The existence of the flame depends entirely upon the combustion of the tallow, the wick being simply a vehicle for its ascent in the melted state. The closely twisted fibres of the wick constitute a number of capillary tubes; hence the liquid tallow is said to rise by capillary attraction (Latin, *capillus*, a hair).

The phenomenon in this case, however, is simply one of suction; for the ignition of the wick at starting causes the ascent of the air in the fine hair-like tubes, and the melted matter immediately rises to fill up the vacuum, and undergoes decomposition at the summit. Without the wick we should have a furious conflagration instead of the slow combustion of a continuous stream of inflammable liquid.

The wick, consisting of cellulose or woody fiber, is principally carbon or charcoal, and consequently chars or becomes blackened during combustion.

It is quite possible to construct a lamp without the aid of any wick at all. We once saw sold in the streets of London an ingenious device for a feeble nightlight at an almost nominal cost. It consisted simply of a wine-glass filled with oil, upon which was floated by means of a piece of cork a small tin tube with a very narrow bore. On the application of a light to the tube, the oil rose by suction and became ignited. The whole cost of the apparatus, including a supply of oil, was one penny.

Before we can understand all about the combustion of our candle, we must learn something of its composition. Like the majority of organic compounds tallow contains carbon, hydrogen, and oxygen—the two first being essential constituents of all highly combustible matter of vegetable or animal origin, as wood, cotton, oil, wax, coal, turpentine, resin, and camphor. The difference in the composition of tallow and wax in 100 parts is given in the following table. A stearine or composite candle differs but slightly in composition from one of wax.

	Tallow.	Wax.
Carbon	77	80
Hydrogen	12	13½
Oxygen	11	6½
	100	100

During combustion these elements enter into new combinations with each other, and with the oxygen of the air, giving rise to a variety of inflammable gasses, the nature of which we must now investigate.

Looking attentively at our candle-flame, we shall notice that it comprises three portions of zones, a dark zone in the center, immediately surrounding the wick ; secondly, a luminous zone, from which its illuminating power proceeds ; lastly, a dimly perceptible external zone called the "mantle." In each of these areas special chemical reactions are taking place. The central zone is the *area of no combustion*, because the gasses evolved from the tallow do not meet with sufficient oxygen for their ignition. This fact can be proved by a very simple experiment. Insert a very narrow glass tube, or the stem of a tobacco pipe into the dark zone, and the unburnt gasses will be drawn off, and may be ignited at the other end.

Another proof that there is no actual flame in this area is furnished by the fact, that, if a match or grain of gunpowder is placed in its center, it will not be immediately ignited, but remain unconsumed till sufficient heat has been absorbed from the surrounding zone. The luminous zone is called the *area* of *partial* or *incomplete combustion ;* because here, the gasses meeting with an inadequate supply of oxygen, are only partially consumed, only part of the carbon is converted into carbonic acid; and the remainder floats about in a white-hot or incandescent state, producing the luminosity, without which the light would be valueless. The external zone or mantle is the *area* of *complete combustion,* because here, the gasses, meeting with the requisite amount of oxygen to oxydize the carbon and unite with the hydrogen are completely burnt; and as there is no solid carbon in this part of the flame, the light is very feeble.

Gasses Burning in the Candle Flame.—We have now to determine what are the gasses given off by the melted tallow or wax.

We have already stated that the elements of the combustible material enter into new combinations with each other and the oxygen of the air under the influence of heat. If we first draw off the gasses contained in the area of no combustion by the method just described, we shall be able to ascertain their nature, and then we can adopt a similar expedient with other zones.

The gaseous products found in the candle flame are carbonic acid, carbonic oxide, olefiant gas, and other hydrocarbons, including marsh gas, hydrogen, nitrogen, and aqueous vapor. It will be necessary to say a few words upon each of these bodies if the reader wishes thoroughly to understand the condition of things in this and other flames, for the combustion of coal-gas, oil, wood, and similar substances, is attended by similar phenomena, and the products of combustion are almost identical.

though differing considerably in relative proportion. One of the most important of these products is *carbonic acid*, or, as chemists prefer to call it, carbon dioxide, because it contains two atoms of oxygen united with one of carbon. It is thus distinguished from carbonic oxide, or carbon monoxide, which has only one atom of oxygen to one of carbon. These bodies are conveniently written $C\,O_2$ and $C\,O$ respectively. As carbonic acid will not burn, it is evolved together with watery vapor, and enters the surrounding atmosphere. In these days of scientific progress every schoolboy is taught something of the properties of carbonic acid. He knows that it is a heavy gas, and, though invisible, can be poured out like water from one vessel into another. He knows, too, that it is one of the cast-off products of respiration, and, consequently, poisonous and irrespirable.

Notwithstanding this, we often take great precautions to prevent its escape. Scared by the ghosts of rheumatism and neuralgia, some people in winter close the doors of their apartments and stop up every crevice by which fresh air can enter or foul air escape.

By means of a sandbag at the window, another at the door, and a piece of list carefully tacked along its edge, the whole arrangement being supplemented by a screen, the products of combustion and exhalation are kept circulating in the room and breathed over and over again by those within, at the cost of morning headache, languor, and depression, with a long train of other evils following in the wake. From the fire, from the lights, and from the lungs of the inmates, the poisonous gas is evolved, and must be removed by efficient ventilation. We are here struck by the remarkable analogy between the process of combustion and the function of respiration.

The latter is, in fact, a species of combustion without flame. The carbon of the impure venous blood unites with the oxygen of the air to form carbonic acid gas, while the hydrogen unites with another portion of oxygen to form water. Both products are expelled at each exhalation, and the chemical action going on within the body raises its temperature to nearly 100°. To prove the presence of carbonic acid in our candle flame, we have only to siphon it off by a bent tube, and pass it into lime water, which will become milky owing to the formation of carbonate of lime or chalk. In the same way we can show the presence of carbonic acid in the breath on simply blowing down a tube into lime water (made by shaking up powdered quicklime with *distilled* water) an immediate precipitate of carbonate of lime will be produced. We all know that aqueous vapor is exhaled from the lungs.

To show its production in our flame invert over it a dry tumbler. In a few seconds the interior will be covered with moisture owing to the condensation of the vapor. *Carbonic oxide* differs from carbonic acid in being combustible, and is, therefore, consumed in the flame. In burning, however, it takes an atom of oxygen from the air, and produces $C\,O_2$ or carbonic acid. It is this gas which burns with a blue flame at the top of our coal fires. The carbonic acid formed at the bottom of the grate, loses half its oxygen in passing upward through the red-hot coals and again reverts to its original condition on combustion. There is consequently no destruction in nature.

What appears to be lost simply assumes another form, and passes into the atmosphere to play another and more important part. What is rejected by man and animals as a poison is the very pabulum of plants, and the chief source of their substance.

Olefiant Gas is an important ingredient in our candle or gas flame, as it is the chief illuminating agent. It is sometimes called heavy carbureted hydrogen, and its formula is written $C_2\,H_4$. Its name—olefiant (oil-making), was given to it on account of the oily liquid which it forms when combined with chlorine.

These compounds of carbon and hydrogen are called *hydrocarbons*, and constitute a very large class. Some of them are solid, as paraffin and naphthalin; others liquid, as turpentine, petroleum, benzol and camphine; and others gaseous, as marsh gas and olefiant gas. As may be expected from their composition, these hydrocarbons are highly inflammable, and burn with a more or less smoky flame in proportion to the amount of carbon they contain. Those which contain the largest number of atoms of carbon capable of uniting with hydrogen, such as paraffin, are called *saturated hydrocarbons*. Paraffin candles are made of a mixture of paraffin and wax, and give a very fair light, because several other "olefines" besides olefiant gas are present in the flame. The illuminating power depends upon the separation of carbon in the solid form, and its incandescence in the zone of incomplete combustion. Olefiant gas, like carbonic oxide, produces carbonic acid by its combustion. We shall describe an easy method of preparing it in the pure form when we come to speak of flames of special interest.

Marsh Gas.—This gas which burns in coal-gas flame as well as in our candle flame is so called because it occurs in nature over stagnant pools and marshes, having been formed by the decomposition of dead leaves and other vegetable matter. It may be collected from these pools by stirring up the mud at the bottom and receiving the bubbles of gas in an inverted bottle filled with water. Marsh gas or light carbureted hydrogen, $C\ H_4$, constitutes the "fire-damp" of coal mines, issuing sometimes in enormous quantities in "blowers" from the coal seams. This gas, like the other hydrocarbons, forms carbonic acid and water by its combustion with oxygen.

Hydrogen.—This is the lightest gas in nature, its weight being one-fifteenth that of common air, on which account it is used for filling small balloons. It forms an explosive mixture with air; and as it is found free in coal-gas it becomes an element of danger wherever there is an escape from the pipes into a closed apartment.

Coal-gas Flame.—The bodies whose properties we have thus briefly summed up are found in coal-gas, the flame of which does not differ much in its chemical reactions from that of a candle. The gas, however, differs much in composition and illuminating power in different towns, the proportion of its constituents varying with the quality of the coal employed, and the temperature to which the retorts are raised. Sometimes the purification of the gas is incomplete; some of the products of the distillation, such as carbonic acid, sulphureted hydrogen, and di-sulphide of carbon, are not only valueless as illuminating agents, but communicate to the gas a disagreeable odor, and must therefore be removed before the gas passes into the gasometer.

These sulphides produce by their combustion sulphurous acid—a gas of a pungent suffocating character; and if present at all in coal-gas may be detected by the application of lead paper, or paper impregnated by a salt of lead. The paper will become blackened by the formation of lead sulphide. The following table represents the composition of coal-gas of good quality:—

Marsh Gas	41·88
Hydrogen	41·71
Carbonic Oxide	4·98
Olefines	8·72
Nitrogen	2·71
	100

In some samples we have found no nitrogen, the whole of that element having united with hydrogen to form ammonia, one of the secondary products of the gas manufacture. The composition of different parts of a coal-gas flame has been examined by

Professor Landolt, who gives us the following results :—

Height from Burner in inches	0·	0·39	07·9	1·18	1·58	1·97
Total volume of Air and Gas before burning	127·08	145·43	272·76	327·73	43·53	481·66
Total volume of Gas after burning	111·41	120·09	245·96	311·37	422·59	461·23
Hydrogen	22·66	14·95	5·49	15·34	14·5	11·95
Marsh gas	33·77	30·2	28·34	21·55	11·92	3·64
Carb. oxide	7·34	14·07	14·05	14·58	22·24	25·14
Olefines	7·29	7·49	7·87	7·94	7·05	5·45
Oxygen	0·66	0·78	0·47	....	..	....
Nitrogen	29·41	38·66	140·7	184·23	270·45	307·1
Carbonic acid	1·94	2·34	10·11	14·98	23·76	32·34
Water	8·34	11·6	38·85	32·58	72·67	75·61

In the column marked "0· *inches*" we have the proportion of gases occurring immediately in contact with the wick, and the distances increase up to 1·97 in., which may be taken as two inches. We find the quantity of hydrogen decreasing up to 0·79 inches, when there is a sudden increase, owing, probably, to its liberation from the watery vapor by the action of the highly-heated carbon at this point. It will be noticed that the quantity of water rapidly increases toward the summit of the flame, where it passes out into the air. A similar increase is observable in the case of the nitrogen, derived from the decomposition of the air, the oxygen of which combines with the carbon and hydrogen to form corbonic oxide, carbonic acid, and water. The nitrogen is an inert body, and does not combine with any of the gaseous matters in the flame; it therefore escapes unchanged. It will be seen that there is no uncombined oxygen above 0·79 in. The increase in carbonic oxide is due to the action of the highly-heated carbon on the carbonic acid, $C O_2$, which parts with one atom of oxygen and becomes $C O$.

Cause of Luminosity in Flame.—We have already stated that the presence of solid carbon in a white-hot state is the cause of luminosity in flame generally. Davy proved this by bringing into contact with the flame a cold substance, when a deposition of soot or carbon was the result. The chemist is acquainted with brilliant flames in which there is no solid matter; but as a general rule the presence of such matter considerably increases the illuminating power. If we project air or oxygen into a flame we destroy its luminosity by dispersing the luminous matter over a wider area, and thereby facilitating the conversion of the carbon into non-luminous gases. We are all familiar with the spluttering blue flame sometimes produced when we first light the gas, in consequence of the admixture of air in the pipes. The reduction of temperature which takes place in this case has much to do with the phenomenon, for we shall presently show that the introduction of nitrogen, steam, or any gas exerting no chemical action on the flame, destroys its luminosity as completely as oxygen. If the air or gas to be passed into the flame is first heated the luminosity at once returns.

It is therefore obvious that the old theory supported by Davy and maintained by other chemists almost up to the present time, respecting the connection between oxygen and flame luminosity, requires modification. The effect appears to be quite as much due to the nitrogen, which, as a reference to the table just given will show, is given off in gradual increasing quantities, and assists in reducing the temperature. The effect produced by mixing air with coal-gas is well seen in the Bunsen burner, which has almost superseded the spirit-lamp, and is universally used in the laboratory for heating flasks, retorts, air baths, etc. It consists of an ordinary gas-burner surrounded by an iron cylinder. At the base of the cylinder there are holes for the admission of air, which rises with the gas to the summit, where the mixture is burnt. The flame is non-luminous, and is not only hotter than an ordinary flame but has the advantage of not blackening the apparatus heated by it. If we stop up the holes at the base, which can be effected by simply turning the cylinder round, the unmixed gas alone rises, and the flame becomes luminous. That this flame is hollow like that of a candle can be shown by passing into its center a match, which will not ignite at once, and also by bringing rapidly down upon it a piece of stout white blotting paper, which will exhibit on withdrawal a charred ring.

The effect of nitrogen or steam upon the non-luminous flame may be tried in the following way:—stop up one of the air holes with a cork, and into the other fix a tube communicating with a gasholder containing nitrogen gas.

The passage of the air being cut off, the flame burns with a bright yellow light, but as soon as the nitrogen gas is allowed to mix with the coal gas, the flame becomes blue and non-luminous. Instead of nitrogen we can send into the burner a current of steam from a flask of boiling water when the same effect will be produced. Conversely we can render a non-luminous flame luminous by raising the temperature of the nitrogen before its introduction into the burner. This can readily be done by fitting a metal tube into the air-hole and connecting it with the delivery tube of the gas-holder. The tube being heated by a lamp placed below it, the temperature of the nitrogen is raised and the flame immediately becomes luminous. Dr. Frankland's recent investigations on the nature of flame have led him to the conclusion that the luminosity of flame is not due to solid carbon, but to a mixture of hydrocarbons capable of condensation like water from steam.

The increase of brilliancy imparted to flame by the presence of incandescent solid matter can be illustrated in various ways. The well-known experiment, so familiar to young chemists, of burning phosphorus in oxygen furnishes an excellent example. When the ignited phosphorus is passed into a jar of the gas by means of a deflagrating spoon, the whole vessel is filled with a most dazzling white light, owing to the dispersion of solid phosphoric acid, $P\ O_5$, produced by the union of the two elements.

When sulphur is burned in the same gas, the blue flame which is produced has not the same luminosity, because the product, sulphurous acid, S O, is not solid but gaseous. The combustion of magnesium affords another illustration of the same principle. The intense white light emitted is due to the presence of solid particles of incandescent magnesium oxide or magnesia when metalic zinc is melted in a crucible, a beautiful luminous flame is seen to play over its surface owing to the formation of solid oxide of zinc in woolly flakes; hence in this state it was formerly known as

"*Philosopher's Wool.*"—The oxyhydrogen flame is scarcely visible in daylight; but if allowed to impinge on a ball of lime to produce the "lime light," we get one of the most brilliant and luminous flames with which we are acquainted. Coal-gas is now usually employed instead of pure hydrogen to mix with the oxygen. In the production of this light the oxygen must be kept in a separate bag, and allowed to mix only with the coal-gas in the burner, which must be of peculiar construction, otherwise the flame might pass down the tube and give rise to a violent explosion.

A safe and easy method of showing the lime light is to fill with oxygen a bag to which a brass cap and long nozzle is fitted, and to force a stream of the gas through a hydrogen flame issuing from a glass tube attached to the bottle in which the hydrogen is prepared. The flame is allowed to impinge upon a cylinder of lime, and intense ignition follows. The cheapest, and perhaps the safest jet that can be used for the lime light is Tate's. It consists of a cylinder of japanned tin plate, six inches high and two inches wide, closed by a cork at its upper end, and standing upon a heavy foot. The blow-pipe jet is con-