FLAME.

A LECTURE

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THE subject that I have to bring before your notice this evening may seem a very simple one, and possibly a vague wonder may fill the minds of many of you as to what is the use of all this apparatus to illustrate such a familiar and commonplace subject. But I trust that before the lecture is finished, you will have found that there is a great deal of interesting information to be derived from a careful study of the very familiar phenomenon of a gas flame.

As I shall have occasion frequently to make use of the word "combustion," I think it is as well in the first place to explain clearly what is meant by this term. In the first place I shall show you what it is not. I take here a piece of platinum wire coiled into a spiral, and I hold this in the flame of a gas lamp, and you see it becomes white hot. This body, however, is not in combustion. When I withdraw it from the flame, it immediately loses both its heat and its light. This platinum coil is not burned—it is not in combustion; it is, as we say, in ignition, or it is incandescent.

I shall now take a more intense flame, that produced by the oxy-hydrogen blow pipe, which is one of the most intense kinds of heat that we can produce. I shall insert in this a piece of lime, and we shall see also the lime glowing or ignited, but at the same time not in combustion. [Experiment.] In this case also the lime was incandescent or ignited, but it was not in combustion. If, however, I put a piece of wood in the flame of the lamp, then we have a totally different phenomenon. When I withdraw tne wood the action is still maintained. We see besides that there is a bodily dispersion of the substance of the wood; whereas in the former case of the platinum, and in the case of the lime, if we weigh the body immediately afterwards we find that it has lost no weight. We see, therefore, that in ignition there is no loss of weight, whereas in combustion there is an apparent loss of weight. I shall take a piece of charcoal and insert this also in the same flame—the oxy-hydrogen flame. You see that it not only emits a strong light, but at the same time it keeps glowing, and will maintain its high temperature for a long time after it has been removed from the source of heat. I now hold a piece of magnesium wire in the flame of this gas lamp, and you see that it is not only ignited, but it is actually burning. We have in this case the magnesium, not incandescent, but in combustion. These examples, therefore, are sufficient to show the fundamental difference between these two states.

Now let us consider a little more minutely this phenomenon of combustion. I have already said that there is an apparent loss of weight. However, when we examine it more minutely, we find that the body which is burning is silently combining with the oxygen of the air. I take it for granted you all know that the atmosphere which we breathe consists of about one-fifth of its bulk of oxygen, and it is this oxygen which bestows upon the atmosphere its positive properties, by which it is enabled to support the respiration of animals and the life of plants. Well, this oxygen during the process of combustion is silently but constantly uniting with the body which is being burned; so that we have a new substance produced, a substance, namely, which is a mixture of oxygen plus the burning body. When I burn carbon or charcoal, therefore, in common air, we have as the product of that combustion a mixture of carbon and oxygen which is called carbonic acid. Of course, the product that is formed will depend upon the particular combustible that is made use of. Now, I have already mentioned that it is the oxygen which is thus combined with the combustible body. If we had an atmosphere of pure oxygen, then the process of combustion would go on much more rapidly, in the same way that the process of respiration would go on much more rapidly; in fact it would go on too rapidly for our frames. If we inhale a few mouthfuls of pure oxygen it has an exhilarating effect upon the system; but if the process is continued too long it induces fever; and small animals, such as mice or rabbits, when plunged into a jar containing pure oxygen, in a very short time are killed by its too violent action. So that it is necessary in the atmosphere to have the positive property of oxygen diluted, as it were, with four times its bulk of a neutral gas—nitrogen. I shall now show you that in oxygen the process of combustion goes on much more vividly. We have here three large glass globes which are filled with oxygen gas. Of course the gas is invisible, but they have been filled beforehand. We now invert one of the jars over a little cup which contains phosphorus, and another is inverted over a cup which contains sulphur; and the globe nearest me is inverted over pieces of charcoal. The whole are connected by wires proceeding from a battery under the table, and when the contact is made, the current flying along the wire will raise to a red heat the small piece of platinum wire passing over these combustible bodies. You see the phosphorus is beginning to burn first; and you see how vividly the process of combustion goes on in an atmosphere of pure oxygen. [The experiments were brilliant, and, like the succeeding experiments, were successful and much applauded.] I shall now show you that when we heat iron and play on it with oxygen we can even burn solid iron. Here are a number of common nails put into a cavity scooped out in a firebrick, where we are heating them, and when heated to a sufficient temperature the pure oxygen will be turned on. [Experiment, with the emission of countless brilliant sparks.] Thus you see solid iron burned. Here is another example of a piece of iron plate which we will show you can be burned right through by the same agency. You see that a small piece of iron has been burned out of this plate of metal by the oxygen. These examples therefore are sufficient to show that in an atmosphere of pure oxygen the process of combustion would go on too rapidly.

Now some substances require a much higher temperature to unite with oxygen than others do. The process of combination may go on at all temperatures; but it is not the mere combination with oxygen that produces combustion. If we expose a piece of bright pure iron to the atmosphere, we observe that in a short time it becomes covered with rust. Well, the action is much the same in this case, for we have the iron uniting with the oxygen to form a new body; in fact, the rust that is formed is a definite product of iron and oxygen, and is called an oxide of iron. Here the iron unites at a very low temperature with the oxygen of the air. In this case heat is given out, as in all cases where chemical union between two bodies takes place. Of course the amount of heat is necessarily very small; but it can be estimated, and it is found to be invariably constant, that is, the same weight of iron will always, in uniting with oxygen, give out precisely the same amount of heat; and, of course, if we spread the operation over a long time, the intensity of the heat is so much the less, and by making the iron combine much more rapidly with the oxygen, we thereby diminish the time in which the action takes place, and consequently we increase the intensity of the resulting action.

Oxygen, therefore, is a body whose presence is essential in all cases of combustion. There are other bodies which are commonly called combustible, but erroneously, because oxygen is as much combustible as the other bodies to which we are about to refer. Of our other combustible bodies I shall take as specimens hydrogen and carbon, because these are the principal ingredients in all our common burning bodies, such as common gas, candles, the oil of lamps, and the coal of our fires; in fact, all our ordinary sources of artificial light are derived either from carbon or hydrogen, or a mixture of the two. Now hydrogen, in uniting with oxygen, generates steam; that is to say, water is a definite combination of oxygen and hydrogen; so that in every case of combustion, where hydrogen is one of the bodies and oxygen the other, we find that the product of the combustion takes the form of steam or water. I shall now show that when hydrogen is burned water is formed. I have here a large bell jar, which you will observe is perfectly clear; there is no dimness upon it. The glass will be held over the burning hydrogen, and in a short time you will notice it is bedimmed with dew. You see at once that it has become dim. Now, if we were to hold it long enough over the burning hydrogen, this dimness would increase, and ultimately the little particles of moisture would unite and form drops of water. We see, therefore, that steam, or water, which is simply steam in a different form, is a compound of oxygen and hydrogen, and is always therefore a necessary product of combustion when these two bodies burn together. Now, in what proportions are the two mixed in order to form water? In the proportion of one part by weight of hydrogen to eight of oxygen. If we mix the two gases in this proportion we can then, instead of burning the hydrogen silently, burn it as it were instantaneously, and an explosion is the result. Here is a small glass bulb, which has been previously filled with a mixture of these two gases derived from the decomposition of water. The water was resolved by means of the voltaic current into its two elements, and the two gases that resulted from the decomposition were received into this bulb. You notice these two upright wires proceeding from our battery, and connected by a short platinum wire, which you see is raised to a white heat when I make contact. I now uncork the bulb, invert it over the wires, and make contact. [The first trial of this experiment failed, in consequence of the intense heat having melted the wire.] We will replace it by a fresh wire. [A loud explosion, the glass bulb being shivered into a thousand fragments.]

A characteristic property of hydrogen is its extreme lightness; it is one of the lightest bodies that we know, being only the fifteenth of the weight of its bulk of air. If a balloon is filled with pure hydrogen, its buoyancy is sufficient to overcome the weight of the envelope, and the balloon rises very rapidly. In practice large balloons are not filled with this gas, as its preparation on a large scale is attended with considerable expense; but a cheaper, though considerably heavier substitute, coal gas, is used. Here are two balloons which have been filled with hydrogen gas. [The balloons, when released, rose rapidly to the ceiling and remained there]. The mouths of these balloons have been purposely left a little open, so that the hydrogen may gradually escape; and, of course, as it escapes its place is filled by air, and consequently the balloons will gradually descend. Having now considered some of the properties of hydrogen, let us now examine carbon, which is one of the commonest combustible bodies that we find around us.

A piece of charcoal, for example, is almost pure carbon. Plumbago or blacklead is another form of carbon. Now, when carbon is united with oxygen, we have two products formed—carbonic acid is one, and carbonic oxide is the other. These two, however, differ in the amount of oxygen which they contain. If we burn charcoal in a limited supply of oxygen, we have carbonic oxide produced, where we have one equivalent of carbon to one of oxygen. But if we burn carbon in a plentiful supply of oxygen, so that the carbon can unite with as much oxygen as it pleases, we have carbonic acid produced, which contains twice as much oxygen as the other compound does. I have got a jar here which contains carbonic acid, and you will observe that it is perfectly colourless. However, it has a great many very active properties. It at once extinguishes combustion, so that if I were to plunge this lighted taper into it, the taper would be extinguished. I shall pour this invisible gas from one glass jar into another with a lighted taper at the bottom: you will see nothing pass, but you will notice that it extinguishes the flame. [Experiment.] You see the flame is at once extinguished. I shall now put the flame into a jar which contains both oxygen and carbonic acid. We have oxygen in the upper part, and carbonic acid in the lower part of the jar. In a short time these two gases would mix, but at present they occupy different positions in the vessel. The flame is now in the oxygen, and burns brightly; it is now in the carbonic acid, and is immediately extinguished. This experiment requires to be done very quickly, because however different the densities of the two gases are they soon mix. We see from these experiments another property of carbonic acid—its great weight; for it admits of being poured like water from one vessel into another, and lies for a time at the bottom of a vessel with oxygen above it. With all gases that are lighter than common air we have to invert the process, and pour the light gas upwards. Now as carbonic acid is destructive of combustion it is equally fatal to the respiration of animals; a few inhalations of the pure gas would bring on insensibility, and if the process were continued for two or three minutes death would be the result. As this gas is a constant product of combustion, you see it is necessary in cases where combustion is going on that there should be a free ventilation in order to carry off this noxious product. I daresay many of you have read of melancholy instances of persons falling asleep in ill-ventilated rooms with a stove or fireplace filled with burning charcoal, and never awaking. They were poisoned by the carbonic acid. Carbonic oxide, as I have said, is produced where there is a limited supply of oxygen. You may frequently have observed in a common fireplace the upper part of the fire burning with a pale blue flame. This is the flame of carbonic oxide, which is therefore very different from carbonic acid. The one is incombustible and extinguishes flame; the other burns with a bluish flame. I have here a jar of carbonic oxide, and on applying a lighted taper to it we shall find that instead of extinguishing the taper, the gas itself burns. [Experiment.] In a common fireplace the carbonic oxide is formed thus—the oxygen of the air entering the lower part of the fire and there meeting with the glowing coals, the carbon of the coals and the oxygen form carbonic acid. As this gas ascends through the burning charcoal which lies above, it is deprived of part of its oxygen and is converted into the lower oxide or carbonic oxide which burns with a pale blue flame in the upper part of the fireplace. This blue flame frequently appears of a purplish tint, as it is often seen on a red background of hot brick.

We have now considered separately hydrogen and carbon, which are the burning bodies; and oxygen, which is said to be the supporter of combustion, although I prefer to designate all three by the same title, and call them all combustible bodies, because the process of combustion is simply a process of union. So that combustion may be defined to be chemical action in which so much heat is given out as to produce light. If, now, our burning body be a gas—in other words, if we have a gas in this process of uniting with oxygen, then flame is the result. So that we may define flame to be gas in a state of combustion.

Now, I shall take coal gas as our typical gas. I shall fill this large wide-mouthed hollow globe partly with coal gas and partly with common air. At present it is full of air, the same as we have in this room; but I shall introduce for a few seconds the open end of this flexible tube which communicates with the gas pipes. I drop a piece of lighted paper into the vessel, and I wish you to observe the nature of the resulting flame. [Pale, but loud-roaring flame.] You observe that instead of burning in the ordinary and quiet way, and giving out a great amount of light, it burns rapidly, and gives out very little light. We see, therefore, that the manner in which gas burns depends a good deal on the manner in which we mix the oxygen of the air with it. Now when we begin to analyse coal gas, and try to find out of what ingredients it consists, we find that it is a very complex substance; but that the valuable ingredients are hydrocarbons, or compounds of carbon and hydrogen. Olefiant gas is the most valuable constituent in coal gas; and the more we have of this olefiant gas—or as it is sometimes called heavy carburetted hydrogen—the higher is the illuminating power. Here is a jar of olefiant gas; you notice the flame with which it burns. [Experiment.] It burns with a dense white flame. I shall afterwards have to explain why in this case we had a great deal of light, and in the former very little. This olefiant gas is a compound of carbon and hydrogen, in the proportion of one part by weight of carbon to two of hydrogen. I can demonstrate the presence of solid carbon in this invisible gas. I have got here two jars, one contains olefiant gas and the other chlorine gas. Now, I shall allow these two gases to mix, by placing the open mouth of the one vessel over that of the other. I shall now apply a light to the mixture, and you will observe that the burning of the mixture is attended by the deposition of a large quantity of soot. [A tall column of dense smoke and soot was produced.] Here we have the carbon distinctly visible, and it comes only from the olefiant gas, because the other gas, the chlorine, contains not a particle of carbon. When olefiant gas is mixed with oxygen in the proportion of one part gas by measure to three of oxygen, an explosive compound is formed. Mr. Harrison will show us some soap bubbles filled with this mixture and explode them. I have here got a small flask filled with the mixture, and I will explode it by applying a light to it. Mr. Harrison has here made a large cauliflower-like head of many soap bubbles in a saucer, and we will explode the lot. [All loud explosions.] This olefiant gas whose properties we have been considering is that constituent in coal gas to which, as I have said, the latter owes its illuminating power. Generally, in good gas, there is about one-fifth part by volume of this gas present. There is a larger volume, however, of another compound of carbon and hydrogen, called marsh gas, or light carburetted hydrogen, the proportion being from two to two and a half, and sometimes three times the volume of the heavy carburetted hydrogen. This marsh gas, as its name implies, is frequently formed in stagnant water, if decaying vegetable matter is at the bottom of the pool. You have I dare say frequently noticed bubbles of gas rising in these stagnant pools and bursting at the top. These are bubbles of marsh gas or light carburetted hydrogen. I have got here a jar of this gas, and I will burn it. You observe that it burns with a whitish flame, much paler than the corresponding flame of the heavy carburetted hydrogen. Now this marsh gas is not only formed from decaying vegetable matter at the bottom of stagnant pools, but it is frequently formed in large quantities in the seams of coal mines, and it forms then what miners call "fire damp." Frequently in coal mines this gas is generated in enormous quantities, and when a reservoir of it is tapped the gas issues in great volume and with great velocity from the orifice, forming what miners call a "blower." Now, if this gas is mixed with about twice its volume of oxygen, or ten volumes of common air, it forms an explosive mixture. Consequently we can understand how it is that dreadful explosions sometimes take place in coal mines. The dangerous fire-damp or marsh gas produced from the layers of coal becomes mixed with the atmosphere in the mines, and when the proper proportion is obtained, and a light applied to the mixture, it at once explodes; and the result of the explosion is that carbonic acid is generated; so though the unfortunate miners should escape being hurt by the explosion, they are in great danger of being poisoned by the carbonic acid which is thus formed, and which the miners call "choke-damp," and sometimes "after-damp." I shall by and by have to call your attention to the Davy lamp, which is an admirable precaution against the occurrence of these very dangerous explosions.

Let us now consider attentively this flame, which we know to be gas in a state of combustion. I shall suppose, for the sake of simplicity, that our gas is entirely composed of the two whose properties we have lately been examining, namely, the two carburetted hydrogens, light and heavy. The gas, as it is being conducted along the pipe to the lamp is, of course, not allowed to mix with the air, with which it comes in contact only when it has reached the opening of the burner. Here on applying heat we determine the union of the oxygen with the carbon and hydrogen. If each particle of carbon and hydrogen had its share of oxygen close beside it, the union of the whole would be instantaneous, and we should have very little light. The luminosity of the flame depends upon the fact that the process of union is not instantaneous but gradual. We find that in the middle of the flame there is pure gas; immediately surrounding this dark region we have a luminous envelope; and if the atmosphere of this room were perfectly still, we should see the flame with a definite conical shape, and on the extreme border we should notice a very pale bluish flame of great heat but of very little light. So that we distinguish in the flame these three regions —a central region of no combustion, where we have almost unmixed gas; a middle or luminous region; and an outer or non-luminous but very hot region. I now show you that in the middle of this flame we have unconsumed gas. I insert the end of an open glass tube in the middle of the flame, and I allow the gas to rise up the tube. I now set fire to it at the other end; and you see it burning brightly. This experiment proves that the oxygen had not mixed with the gas in the centre of the flame; in fact the burning gas on the outside prevents the oxygen from getting access to it. In the central layer the oxygen of the air has already arrived, but not in sufficient quantity to satisfy both the hydrogen and carbon. Of the two bodies hydrogen most readily unites with oxygen, so that it is burned before the carbon is consumed. Now you have already seen that when hydrogen and oxygen burn they give out great heat but very little light; but the great heat resulting from this combustion heats the particles of carbon to a white heat. And in exactly the same way as when the oxy-hydrogen flame played upon the lime light we had intense light, so now when the union of the hydrogen and oxygen heats the little particles of carbon to a white heat, we have a luminous flame; so that the luminosity of the flame depends upon the fact that the hydrogen burns before the carbon. In the outer region where the oxygen has ready access to both the hydrogen and carbon then we have the complete combustion of both the hydrogen and carbon. If I mix the gas with air before setting fire to it at the top, the character of the flame will be altered. The chimney of this gas lamp is provided at the bottom with a little cap, by turning which round four holes are opened, and consequently the air of the room is allowed to enter and mix with the gas as it rises in the chimney; and when the mixture is set fire to it burns with a different flame; in other words, the oxygen has been mixed with the gas, and the carbon and hydrogen are now burning simultaneously, consequently there are no carbon particles to be heated to a white heat, and the flame is feebly luminous. I have here a piece of wire gauze, and I wish to show you that the flame won't pass through it. I press the gauze down upon the flame, but it won't pass through. Now that there is gas above the gauze I can show by setting fire to it on the other side. You observe that the gas burns at the top, though the flame won't pass through. Not only so, but I can first allow the gas to pass through and ignite it at the top of the gauze, but the flame will not pass through to light the gas which we know to be below. This shows very distinctly that wire gauze serves as an obstacle, as it were, to prevent the passage of the flame through it. Now, Sir Humphrey Davy made use of this property of wire gauze in constructing his very ingenious and exceedingly useful safety lamp Here is a safety lamp of the ordinary construction. You will notice that it consists of a common oil lamp, with a cylindrical chimney of wire gauze, which will allow, of course, the oxygen of the air to pass through and maintain the combustion of the oil within, but, if there is a combustible gas on the outside, the flame cannot pass through to set fire to it.

Now suppose we have this protected flame in an atmosphere of marsh gas. The gas may pass through the little meshes of the gauze, and may burn inside the hollow cylinder; but the flame cannot pass outwards; so that we can carry with impunity this protected light through a combustible and even explosive atmosphere. I shall immerse the Davy lamp in an explosive gas, and you will see that the protected flame cannot pass out to set fire to the explosive gas on the outside. You already see that the gas has passed within and burns, but the flame cannot pass out to set fire to the gas on the outside. I shall now show you that there is combustible gas on the outside by setting fire to it. [Experiment.] So that the Davy lamp would serve as a perfect protection in mines, if only the miners would use it carefully. And in fact it not only serves as a preventive of accidents, but it also serves as a warning of the existence of a dangerous gas in the mine; for as soon as a miner sees his lamp glowing within, he knows that some of the fire damp has passed within his lamp, and, consequently, that it is time for him to be leaving the mine. It is entirely through the recklessness of miners, who will persist in unscrewing the gauze of their lamps in order to light their pipes, that the melancholy accidents take place that we so frequently read about. I am speaking, of course, only of those accidents which arise from explosions owing to the use of naked lights.

We have now seen that when certain gases are mixed with a proper proportion of oxygen, the combustion is instantaneous, in other words, there is an explosion. Now I dare say most of you know that when a series of noises take place with great enough rapidity, a musical note is produced. If, now, I can mix a burning gas with a limited supply of oxygen, so as to make it explode; and if I can make these explosions follow each other sufficiently fast, we shall have a musical note produced; or, in other words, we shall have a musical flame. This musical flame was first observed about one hundred years ago by Dr. Higgins, a Dublin gentleman, who was burning hydrogen, and who found that when a small jet of burning hydrogen was protected in a measure from the external atmosphere by placing a glass tube over it open at both ends, the little hydrogen flame emitted a musical note. But it has been found that hydrogen is not the only gas which emits musical notes; in fact, any gas which admits of being burned can be made to emit a musical note.

Here is a small jet of coal gas burning at a common gas burner, which can be made to sing by placing a tube of glass over it. [Experiment.] The pitch of this note depends upon the length of the tube; so that if I take a longer tube, I shall get a graver note; but if I take a shorter tube, I shall get a higher note. I shall now place a much shorter tube over another flame, and you will hear a different tone produced. [Two notes of different pitch were now heard.] I have got a series of four pipes here of such lengths that when they are placed over their flames we have the common chord produced; that is to say we have one note a third above the first, another a fifth above it, and the fourth the octave of the first. I shall now place them all in position, and you will hear the common chord sounded. [The four notes of the common chord were heard distinctly.] By checking the supply of air, I can stop the singing of any flame. In this way it would be possible, theoretically at any rate, to construct a musical instrument if we had a series of pipes arranged, with appliances to stop and open the tubes at will. If we examine attentively the condition of one of these singing flames we find that, unlike an ordinary flame, it does not burn steadily, but it is in a violent state of commotion—it is dancing up and down. And not only so, but it can be shown to you that the little singing flame is periodically extinguished; in fact, the whole explanation of this phenomena is, that a limited supply of oxygen having mixed with the air, an explosion succeeds immediately. The gas is again mixed with its proper dose of oxygen, relit by the intense heat, and another explosion takes place; so that we have these processes going on consecutively—the gas issuing from the orifice, mixing with its limited dose of oxygen, taking fire and exploding; again being mixed and again exploding, and so on, the whole operation going on many hundred times in a minute. I shall now show you on a larger scale that our singing flame is not only quivering violently, but at the same time is actually extinguished and lit alternately. The arrangement I have got for this is very simple. I have a large tube, in order to have as large a flame as possible; then by means of this concave mirror behind it I can reflect a magnified image of this flame upon a transparent screen in front of you; and you can see already, when the mirror is steady, that the flame is quivering. I now make the mirror revolve rapidly, and you notice that we have a series of tongues of fire, as it were, arranged along the screen. If you watch closely these different tongues, you will see an absolutely black interval separating the bright images. The explanation of this is that we have here an image, not of say a dozen jets which are burning at the same time, but an image of a dozen which were burning at different times. You must accept it as a fact that an impression of light received into the eye lasts for about the tenth part of a second; so that if the light of any object should fall ten times on the eye in a second, we have the impression of a continuous light. For example, when we twirl a string, with one extremity burning, quickly round, we see a continuous circle of fire. This is because the impression of the light has remained for a certain definite portion of time upon the retina. Precisely in the same way here, the image of each flame is thrown upon the screen, and the effect remains upon the retina of the eye for some little time, the series of flames succeeding each other so rapidly that we see the images of a considerable number of them upon the screen together; that is to say we have an image of about ten or twelve flames which exist actually at different portions of time, though we see their images simultaneously. Now, as there are black intervals between these luminous tongues, it is evident that between the existence of one flame and the next there must have been a time when there was absolute darkness; in other words, our flame was burning and extinguished, burning and extinguished, and this, of course, so quickly that we have the impression of a continuous light.

I shall next show you that one of these singing flames can start another one into song, provided we have over it a tube which will be capable of resounding to the same note. I have here a small flame which can be made to sing in the usual way; then at some little distance from it I have a similar flame provided with a similar tube; but I adjust the tube over one so that it shall remain perfectly still. The moment I place the tube over the second flame it will begin to sing; and after a little it will shake its neighbour into song. This is an illustration of a general law in physics, namely, that bodies which can emit a wave of a certain kind are also able to absorb a wave of precisely the same sort. You see the two flames here which are separated by a considerable interval; one of them is burning quite still, and it might remain in this quiescent state for any length of time. I place a tube over the second one so as to make it sing, and after a short time you will hear not one note but two. Now you hear two notes in unison. The second one has been started as it were by the action of the first.

Again, by lowering the tube upon the first I cause it to give a different note, and you perceive that the second one does not now respond to it; it is quite dumb. A flame will respond to a note of its own wave length, but it will not respond to a note of a different wave length. This is a phenomenon of exactly the same kind as that a body will absorb heat rays of the same sort that it will itself give out when heated. Or again, a piano wire, when stretched, can emit a particular note, and if we sound that same note in its immediate neighbourhood the stretched wire of the piano will respond to it, and will give out the same note. Again, many of you know that when a glass partly filled with water is rubbed by a wetted finger, it gives out a certain note. If I strike this note strongly on a piano, or on the string of a violin, I can make the glass respond to it. These are a few examples of bodies absorbing that sort of wave which they are able themselves to give out.

Some of you may perhaps have observed that when a gas flame is on the point of flaring it is in a particularly sensitive condition, and noises made near it seem to affect it; and often the flame, instead of burning quietly, will throw out long tongues of fire. Workmen have frequently noticed, for example, in manufactories, that a creaking noise made by their tools at certain times in the evening, when the gas is at a considerable pressure, will exercise a remarkable influence upon the gas, which is seen to jump up and down when these noises are produced. Musicians also, at concerts, have noticed the same thing—that when the gas is on the point of flaring, certain notes made the gas respond, as it were, to those notes. I have got here an ordinary fish-tail burner, and the pressure is so regulated that it is in this sensitive condition. You see that a little squeaking noise makes it respond at once. [Experiments.] And even if the noise be made at a considerable distance, say at the end of the room, the same result will follow, and the flame will respond to this peculiar noise. I shall now take a bat's-wing burner. You see this also responds, although not so much as in the last example, still it evidently responds to every noise that is made. I shall now take a much more sensitive flame. I shall take a jet which issues from a glass tube drawn out to a fine point. We have got a long jet which burns with a sort of excrescence at the top. Let us so regulate the pressure as to get this just on the point of flaring, but not actually flaring. There is now a flame which you will find to be particularly sensitive to different sounds. [Illustrations of an amusing nature, in which the audience took part.] You find that the flame is not only sensitive to this squeaking noise, but to many different sounds. If I make a noise by clapping my hands, you see it responds. [The audience clapped.] The flame responds energetically to the noise which you make. It is not the puffs of air which you generate by clapping hands that affects the flame; it is the waves caused by the noise itself, for when we puff upon this flame with a bellows, gently, not directly upon the flame but a little to one side, the silent puffs of air do not affect it as the noise does. These singing flames will respond not only to squeaking noises and the clapping of hands, but to the sounds of certain letters—if I hiss, for example, at it. [The lecturer sounded the letter *s* strongly.] It is very sensitive to the sound of the letter *s*. [The flame jumped when the letter *r* was trilled, and danced again when the audience hissed.] It is by regulating the width of the orifice of the gas and the pressure that we get the flames that are sensitive to different sounds. Generally the higher the pressure is the higher also is the note to which the gas will respond. I might strike certain notes on the piano, but to certain of them it would be quite dumb, whilst to others it would violently respond.

Now, what is the explanation of this somewhat singular phenomenon? Why is it that flame should be in this critical condition, so as to respond to very slight sounds indeed? In fact, our flame seems to resemble one of those large rocking stones that you may possibly have read of as occurring in many parts of England, especially in Cornwall. These large masses of stone are sometimes so delicately poised that the slightest touch of the hand will make them rock; hence they are called logging or rocking stones. Now, our sensitive flame here seems to be in this critical condition. It is, as it were, on the edge of a precipice, so that a slight force serves to push it over. But how is it that a noise of a certain sort will make it respond? The shrinking of a tall flame into one of less than half its height is equally produced when the pressure on the gas is slightly increased, so that the effect is due to a change of pressure. The pressure with which the gas emerges will depend, in the first place, upon the weight placed on the gas-bag, and, in the second place, upon the width of our orifice.

Now, if while the gas is issuing the orifice be contracted, it is quite clear that the pressure is virtually increased. And certain sounds can throw the tubes through which the gas is issuing into vibration—namely, those sounds which the tubes can themselves emit. If, therefore, I sound such a note that our glass tube vibrates in response to it, then we have the orifice alternately contracted and expanded; and, therefore, the pressure of the gas will be correspondingly altered. It is in consequence, therefore, of this varying pressure caused by the alternate contraction and expansion of the orifice that the sudden shrinking of the flame is produced.

I shall now show you, before bringing this lecture to a close, an experiment which I dare say many of you have seen before; but I wish to draw a different lesson from it to what was derived when you saw the experiment performed in Dr. Roscoe's last lecture. I have here a large Bunsen gas lamp of the ordinary construction. I set fire to the gas, and of course it burns with the ordinary non-luminous flame. Now I shall render this luminous by introducing into it a little carbonate of soda. If you now look at any coloured objects in the room, you will see that instead of being of their usual tint they are of a ghastly yellow hue; and if you examine your own and your neighbour's hands and faces you will see the same corpse-like tint. I wish you also to notice that while colours generally appear of this ghastly yellow, any black object still appears black. I shall repeat the experiment, and I wish you to look at your black coats. You will find that they are still black, while all other colours than black are changed. Now I wish to derive from this simple experiment some information as to the natural colours of bodies. How is it, for example, that some bodies appear red, others blue, others orange? In other words, to what is it that bodies owe their natural colour? This experiment shows us that it is not something inherent in the body itself, because if a piece of red cloth were inherently red, it ought to be red in whatever light we examine it. Clearly, therefore, the red colour is not inherent in the object itself; it somehow or other owes its colour to the light which falls upon it. Now you have in previous lectures been shown that white light consists of a great many different colours; that you have, for example, red, orange, yellow, green, blue, indigo, and violet, mixed in white light. Now when this white light falls upon bodies, some of it will be reflected and part of it will be absorbed; and each different object, of course, will absorb its own definite colour or set of colours, and will reflect to our eye the remainder. It is because the piece of red cloth, for example, reflects the red rays and absorbs all the others, that it appears to us to be red. Again, a piece of black cloth appears black because it absorbs all the colours and reflects none. But I should guard this expression, and say not that a piece of red cloth, for example, reflects only red rays, but, rather, that it reflects the red rays in greater abundance than the others. It does reflect a few others; it reflects, for example, a little orange and yellow, but no blue. Similarly a blue object reflects principally blue rays, but it will also reflect a few yellow ones, but hardly any red ones. So that if we change the character of the light which falls upon objects, we of course change their colours. Now the light which you saw last differs from white light in being a perfectly pure light; that is, it is not a mixture of light of different colours, but consists only of yellow rays. So that if an object is not able to reflect any yellow rays, then when such an object is illuminated by this pure light it will appear, of course, to be black, simply because it is not able to reflect any rays at all. This will explain how it is that your black coats still appear black. A red object does not appear black in this light, as it would do if it reflected only red rays, but as it is able to reflect a few yellow rays it appears of a pale yellow colour. Thus all coloured objects will change their colour according to the nature of the light by which they are illuminated, and in the absence of all light, that is in darkness, are of course black.