LECTURE II

A CANDLE: BRIGHTNESS OF THE FLAME-AIR NECESSARY FOR COMBUSTION-PRODUCTION OF WATER

WE were occupied the last time we met in considering the general character and arrangement as regards the fluid portion of a candle, and the way in which that fluid got into the place of combustion. You see, when we have a candle burning fairly in a regular, steady atmosphere, it will have a shape something like the one shown in the diagram, and will look pretty uniform, although very curious in its character. And now I have to ask your attention to the means by which we are enabled to ascertain what happens in any particular part of the flame; why it happens; what it does in happening; and where, after all, the whole candle goes to; because, as you know very well, a candle being brought before us and burned, disappears, if burned properly, with- out the least trace of dirt in the candle stick; and this is a very curious circumstance. In order, then, to examine this candle carefully, I have arranged certain apparatus, the use of which you will see as I go on. Here is a candle; I am about to put the end of this glass tube into the middle of the flame-into that part which old Hooker has represented in the diagram as being rather dark, and which you can see at any time if you will look at a candle carefully, without blowing it about. We will examine this dark part first. Now I take this bent glass tube, and introduce one end into that part of the flame, and you see at once that something is coming from the flame, out at the other end of the tube; and if I put a flask there, and leave it for a little while, you will see that something from the middle part of the flame is gradually drawn out, and goes through the tube, and into that flask, and there behaves very differently from what it does in the open air. It not only escapes from the end of the tube, but falls down to the bottom of the flask like a heavy substance, as indeed it is (FIG. 61). We find that this is the wax of the candle made into a vaporous fluid-not a gas. (You must learn the difference between a gas and a vapor: a gas remains permanent; a vapor is something that will condense.) If you blowout a candle, you perceive a very nasty smell, resulting from the condensation of this vapor. That is very different from what you have outside the flame; and, in order to make that more clear to you, I am about to produce and set fire to a larger portion of this vapor; for what we have in the small way in a candle, to understand thoroughly, we must, as philosophers, produce in a larger way, if needful, that we may examine the different parts. FIG. 61 And now Mr. Anderson will give me a source of heat, and I am about to show you what that I vapor is. Here is some wax in a glass flask, and I am going to make it hot, as the inside of that candle flame is hot, and the matter about I the wick is hot. [The lecturer placed some wax in a glass flask, and heated it over a lamp.] Now I dare say that is hot enough for me. You see that the wax I put in it has become fluid, and there is a little smoke coming from it. We shall very soon have the vapor rising up. I will make it still hotter, and now we get more of it, so that I can actually pour the vapor out of the flask into that basin, and set it on fire there. This, then, is exactly the same kind of vapor as we have in the middle of the candle; and that you may be sure this is the case, let us try whether we have not got here, in this flask, a real combustible vapor out of the middle of the candle. [Taking the flask into which the tube from the candle proceeded, and introducing a lighted taper (FIG. 62).] See how it burns. Now this is the vapor from the middle of the candle, produced by its own heat; and that is one of the first things you have to consider with respect to the progress of the wax in the course of its combustion, and as regards the changes it undergoes. I will arrange another tube carefully in the flame, and I should not wonder if we were able, by a little care, to get that vapor to pass through the tube to the other extremity, where we will light it, and obtain absolutely the flame of the candle at a place distant from it. Now, look at that. Is not that a very pretty experiment? Talk about laying on gas-why, we can actually lay on a candle! And you see from this that there are clearly two different kinds of action- one the production of the vapor, and the other the combustion of it-both of which take place in particular parts of the candle. FIG. 62 I shall get no vapor from that part which is already burnt. If I raise the tube (FIG. 61) to the upper part of the flame, so soon as the vapor has been swept out what comes away will be no longer combustible; it is already burned. How burned? Why, burned thus: - In the middle of the flame, where the wick is, there is this combustible vapor; on the outside of the flame is the air which we shall find necessary for the burning of the candle; between the two, intense chemical action takes place, whereby the air and the fuel act upon each other, and at the very same time that we obtain light the vapor inside is destroyed. If you examine where the heat of a candle is, you will find it very curiously arranged. Suppose I take this candle, and hold a piece of paper close upon the flame, where is the heat a of that flame? Do you not see that it is not in the inside? It is in a ring, exactly in the place where I told you the chemical action was; and even in my irregular mode of making the experiment, if there is not too much disturbance, there will always be a ring. This is as good experiment for you to make at home. Take a strip of paper. I have the air in the room quiet, and put the piece of paper right across the middle of the flame -(I must not talk while I make the experiment) -and you will find that it is burnt in two places, and that it is not burnt, or very little so, in the middle; and when you have tried the experiment once or twice, so as to make it nicely, you will be very interested to see where the heat is, and to find that it is where the air and the fuel come together. This is most important for us as we proceed with our subject. Air is absolutely necessary for combustion; and, what is more, I must have you understand that fresh air is necessary, or else we should be imperfect in our reasoning and our experiments. Here is a jar of air; I place it over a candle, and it burns very nicely in it at first, showing that what I have said about it is true; but there will soon be a change. See how the flame is drawing upward, presently fading, and at last going out. And going out, why? Not because it wants air merely, for the jar is as full now as it was before; but it wants pure, fresh air. The jar is full of air, partly changed, partly not changed; but it does not contain sufficient of the fresh air which is necessary for the combustion of a candle. These are all points which we, as young chemists, have to gather up; and if we look a little more closely into this kind of action, we shall find certain steps of reasoning extremely interesting. For instance, here is the oil-lamp I showed you an excellent lamp for our experiments -the old Argand lamp. I now make it like a candle [obstructing the passage of air into the centre of the flame]; there is the cotton; there is the oil rising up in it, and there is the conical flame. It burns poorly because there is a partial restraint of air. I have allowed no air to get to it save around the outside of the flame, and it does not burn well. I can not admit more air from the outside, because the wick is large; but if, as Argand did so cleverly, I open a passage to the middle of the flame, and so let air come in there, you will see how much more beautifully it burns. If I shut the air off, look how it smokes; and why? We have now some very interesting points to study: we have the case of the combustion of a candle; we have the case of a candle being put out by the want of air; and we have now the case of imperfect combustion, and this is to us so interesting that I want you to understand it as thoroughly as you do the case of a candle burning in its best possible manner. I will now make a great flame, because we need the largest possible illustrations. Here is a larger wick [burning turpentine on a ball of cotton]. All these things are I the same as candles, after all. If we have larger wicks, we must have a larger supply of air, or we shall have less perfect combustion. Look, now, at this black substance going up into the atmosphere; there is a regular stream of it. I have provided means to carry off the imperfectly burned part, lest it should annoy you. Look at the soots that fly off from the flame; see what an imperfect combustion it is, because it can not get enough air. What, then, is happening? Why, certain things which are necessary to the combustion of a candle are absent, and very bad results are accordingly produced; but we see what happens to a candle when it is burnt in a pure and proper state of air. At the time when I showed you this charring by the ring of flame on the one side of the paper, I might have also shown you, by turning to the other side, that the burning of a candle produces the same kind of soot-charcoal, or carbon. But, before I show that, let me explain to you, as it is quite necessary for our purpose, that, though I take a candle, and give you, as the general result, its combustion in the form of a flame, we must see whether combustion is always in this condition, or whether there are other conditions of flame; and we shall soon discover that there are, and that they are most important to us. I think, perhaps, the best illustration of such a point to us, as juveniles, is to show the result of strong contrast. Here is a little gunpowder. You know that gunpowder burns with flame; we may fairly call it flame. It contains carbon and other materials, which altogether cause it to burn with a flame. And here is some pulverized iron, or iron filings. Now I purpose burning these two things together. I have a little mortar in which I will mix them. (Before I go into these experiments, let me hope that none of you, by trying to repeat them for fun's sake, will do any harm. These things may all be very properly used if you take care, but without that much mischief will be done.) Well, then, here is a little gunpowder, which I put at the bottom of that little wooden vessel, and mix the iron filings up with it, my object being to make the gunpowder set fire to the filings and burn them in the air, and thereby show the difference between substances burning with flame and not with flame. Here is the mixture; and when I set fire to It you must watch the combustion, and you will see that it is of two kinds. You will see the gunpowder burning with a flame l and the filings thrown up. You will see them burning, too, but t without the production of flame. They will each burn separately. [The lecturer then ignited the mixture.] There is the gunpowder, which burns with a flame, and there are the filings: they burn with a different kind of combustion. You see, then, these two great distinctions; and upon these differences depend all the utility and all the beauty of flame which we use for the purpose of giving out light. When we use oil, or gas, or candle for the purpose of illumination, their fitness all depends upon these different kinds of combustion. There are such curious conditions of flame that it requires some cleverness and nicety of discrimination to distinguish the kinds of combustion one from another. For instance, here is a powder which is very combustible, consisting, as you see, of separate little particles. It is called lycopodium,(7) and each of these particles can produce a vapor, and produce its own flame; but, to see them burning, you would imagine it was all one flame. I will now set fire to a quantity, and you will see the effect. We saw a cloud of flame, apparently in one body; but that rushing noise [referring to the sound produced by the burning] was a proof that the combustion was not a continuous or regular one. This is the lightning of the pantomimes, and a very good imitation. [The experiment was twice repeated by blowing lycopodium from a glass tube through a spirit flame.] This is not an example of combustion like that of the filings I have been speaking of, to which we must now return. Suppose I take a candle and examine that part of it which appears brightest to our eyes. Why, there I get these black particles, which already you have seen many times evolved from the flame, and which I am now about to evolve in a different way. I will take this candle and clear away the gutterage, which occurs by reason of the currents of air; and if I now arrange the glass tube so as just to dip into this luminous part, as in our first experiment, only higher, you see the result. In place of having the same white vapor that you had before, you will now have a black vapor. There it goes, as black as ink. It is certainly very different from the white vapor; and when we put a light to it we shall find that it does not burn, but that it puts the light out. Well, these particles, as I said before, are just the smoke of the candle; and this brings to mind that old employment which Dean Swift recommended to servants for their amusement, namely, writing on the ceiling of a room with a candle. But what is that black substance? Why, it is the same carbon which exists in the I candle. How comes it out of the candle? It evidently existed in the I candle, or else we should not have had it here. And now I want you to follow me in this explanation. You would hardly think that all those substances which fly about London, in the form of soots and blacks, are the very beauty and life of the flame, and which are burned in it as those iron filings were burned here. Here is a piece of wire gauze, which will not let the flame go through it; and I think you will see, almost immediately, that when I bring it low enough to touch that part of the flame which is otherwise so bright, it quells and quenches it at once, and allows a volume of smoke to rise up. I want you now to follow me in this point-that whenever a substance burns, as the iron filings burnt in the flame of gunpowder, without assuming the vaporous state (whether it becomes liquid or remains solid), it becomes exceedingly luminous. I have here taken three or four examples apart from the candle on purpose to illustrate this point to you, because what I have to say is applicable to all substances, whether they burn or whether they do not burn-that they are exceedingly bright if they retain their solid state, and that it is to this presence of solid particles in the candle flame that it owes its brilliancy. Here is a platinum wire, a body which does not change by heat. If I heat it in this flame, see how exceedingly luminous it becomes. I will make the flame dim for the purpose of giving a little light only, and yet you will see that the heat which it can give to that platinum wire, though far less than the heat it has itself, is able to raise the platinum wire to a far higher state of effulgence. This flame has carbon in it; but I will take one that has no carbon in it. The is a material, a kind of fuel -a vapor, or gas, whichever you like I call it-in that vessel, and it has no solid particles in it; so I take that because it is an example of flame itself burning without any solid matter whatever; and if I now put this solid substance in it, you see what an intense heat it has, and how brightly it causes the solid body to glow. This is the pipe through which we convey this particular gas, which we call hydrogen, and which you shall know all about the next time we meet. And here is a substance called oxygen, by means of which this hydrogen can burn; and although we produce by their mixture, far greater heat (8) than you can obtain from the candle, yet there is very little light. If, however, I take a solid substance, and put that into it, we produce an intense light. If I take a piece of lime, a substance which will not burn, and which will not vaporize by the heat (and because it does not vaporize remains solid, and remains heated), you will soon observe what happens as to its glowing. I have here a most intense heat produced by the burning of hydrogen in contact with the oxygen; but there is as yet very little light-not for want of heat, but for want of particles which ca: retain their solid state; but when I hold this piece of lime in the flame of the hydrogen as it burns in the oxygen, see how it glows This is the glorious lime light, which rivals the voltaic light, and which is almost equal to sunlight. I have here a piece of carbon or charcoal, which will burn and give us light exactly in the same manner as if it were burnt as part of a candle. The heat that is in the flame of a candle decomposes the vapor of the wax, and sets free the carbon particles; they rise up heated and glowing as this now glow! and then enter into the air. But the particles, when burnt, never pass off from a candle in the form of carbon. They go off into the air as a perfectly invisible substance, about which we shall know hereafter Is it not beautiful to think that such a process is going on, and that such a dirty thing as charcoal can become so incandescent? You see it comes to this-that all bright flames contain these solid particles; all things that burn and produce solid particles, either during the time they are burning, as in the candle, or immediately after being burnt, as in the case of the gunpowder and iron filings-all these things give us this glorious and beautiful light. I will give you a few illustrations. Here is a piece of phosphorus, which burns with a bright flame. Very well; we may now conclude that phosphorus will produce, either at the moment that it is burning or afterwards, these solid particles. Here is the phosphorus lighted, and I cover it over with this glass for the purpose of keeping in what is produced. What is all that smoke? (FIG. 63.) That smoke consists of those very particles which are produced by the combustion of the phosphorus. Here, again, are two substances. This is chlorate of potassa, and this other sulphuret of antimony. I shall mix these together a little, and then they may be burnt in many ways. I shall touch them with a drop of sulphuric acid, for the purpose of giving you an illustration of chemical action, little and they will instantly burn.(9) [The lecturer then ignited the mixture by means of sulphuric acid.] Now, from the appearance of things, you can judge for yourselves whether they produce solid matter in burning. I have given you the train of reasoning which will enable you to say whether they do or do not; for what is this bright flame but the solid particles passing off? Mr. Anderson has in the furnace a very hot crucible. I am about to throw into it some zinc filings, and they will burn with a flame like gunpowder. I make this experiment because you can make as well at home. Now I want you to see what will be the result of the combustion of this zinc. Here it is burning-burning beautifully like a candle, I may say. But what is all that smoke, and what are those little clouds of wool which will come to you if you can not come to them, and make themselves sensible to you in the form of the old philosophic wool, as it was called? We shall have left in that crucible, also, a quantity of this woolly matter. But I will take a piece of this same zinc, and make an experiment a little more closely at home, as it were. You will have here the same thing happening. Here is the piece of zinc; there [pointing to a jet of hydrogen] is the furnace, and we will set to work and try and burn the metal. It glows, you see; there is the combustion; and there is the white substance into which it burns. And so, if I take that flame of hydrogen as the representative of a candle, and show you a substance like zinc burning in the flame, you will see that it was merely during the action of combustion that this substance glowed-while it was kept hot; and if I take a flame of hydrogen and put this white substance from the zinc into it, look how beautifully it glows, and just because it is a solid substance. I will now take such a flame as I had a moment since, and set free from it the particles of carbon. Here is some camphene, which will burn with a smoke; but if I send these particles of smoke through this pipe into the hydrogen flame you will see they will burn and become luminous, because we heat them a second time. There they are. Those are the particles of carbon reignited a second time. They are those particles which you can easily see by holding a piece of paper behind them, and which, while they are in the flame, are ignited by the heat produced, and, when so ignited, produce this brightness. When the particles are not separated you get no brightness. The flame of coal gas owes its brightness to the separation, during combustion, of these particles of carbon, which are equally in that as in a candle. I can very quickly alter that arrangement. Here, for instance, is a bright flame of gas. Supposing I add so much air to the flame as to cause it all to burn before those particles are set free, I shall not have this brightness; and I can do that in this way: If I place over the jet this wire-gauze cap, as you see, and then light the gas over it, it burns with a non-luminous flame, owing to its having plenty of air mixed with it before it burns; and if I raise the gauze, you see it does not burn below (10). There is plenty of carbon in the gas; but, because the atmosphere can get to it, and mix with it before it burns, you see how pale and blue the flame is. And if I blow upon a bright gas flame, so as to consume all this carbon before it gets 'heated to the glowing point, it will also burn blue. [The lecturer illustrated his remarks by blowing on the gas light.] The only reason why I have not the same bright light when I thus blow upon the flame is that the carbon meets with sufficient air to burn it before it gets separated in the flame in a free state. The difference is solely due to the solid particles not being separated before the gas is burnt. You observe that there are certain products as the result of the combustion of a candle, and that of these products one portion may be considered as charcoal, or soot; that charcoal, when afterward burnt, produces some other product; and it concerns us very much now to ascertain what that other product is. We showed that something was going away; and I want you now to understand how much is going up into the air; and for that purpose we will have combustion on a little larger scale. From that candle ascends heated air, and two or three experiments will show you the ascending current; but, in order to give you a notion of the quantity of matter which ascends in this way, I will make an experiment by which I shall try to imprison some of the products of this combustion. For this purpose I have here what boys call a fire-balloon; I use this fire-balloon merely as a sort of measure of the result of the combustion we are considering; and I am about to make a flame in such an easy and simple manner as shall best serve my present purpose. This plate shall be the "cup," we will so say, of the candle; this spirit shall be our fuel; and I am about to place this chimney over it, because it is better for me to do so than to let things proceed at random. Mr. Anderson will now light the fuel, and here at the top we shall get the results of the combustion. What we get at the top of that tube is exactly the same, generally speaking, as you get from the combustion of a candle; but we do not get a luminous flame here, because we use a substance which is feeble in carbon. I am about to put this balloon- not into action, because that is not my object-but to show you the effect which results from the action of those products which arise from the candle, as they arise here from the furnace. [The balloon was held over the chimney (FIG. 64), when it immediately commenced to fill.] You see how it is disposed to ascend; but we must not let it up; because it might come in contact with those upper gaslights, and that would be very inconvenient. [The upper gas-lights were turned out at the request of the lecturer, and the balloon was allowed to ascend.] Does not that show you what a large bulk of matter is being evolved? Now there is going through this tube [placing a large glass tube over a candle] all the products of that candle, and you will presently see that the tube will become quite opaque. Suppose I take another candle, and place it under a jar, and then put a light on the other side, just to show you what is going on. You see that the sides of the jar become cloudy, and the light begins to burn feebly. It is the products, you see, which make the light so dim, and this is the same thing which makes the sides of the jar so opaque. If you go home, and take a spoon that has been in the cold air, and hold it over a candle-not so as to soot It-you will find that it becomes dim just as that jar is dim. If you can get a silver dish, or something of that kind, you will make the experiment still better; and now, just to carry your thoughts forward to the time we shall next meet, let me tell you that it is water which causes the dimness, and when we next meet I will show you that we can make it, without difficulty, assume the form of a liquid.

7. Lycopodium is a yellowish powder found in the fruit of the club moss (Lycopodium clavatum). It is used in fireworks.

8. Bunsen has calculated that the temperature of the oxyhydrogen blowpipe is 8061^{o} Centigrade. Hydrogen burning in air has a temperature of 3259^{o} C., and coal gas in air, 2350^{o} C.

9. The following is the action of the sulphuric in inflaming the mixture of sulphuret of antimony and chlorate of potassa. A portion of the latter is decomposed by the sulphuric acid into oxide of chlorine, bisulphate of potassa, and perchlorate of potassa. The oxide of chlorine inflames the sulphuret of antimony, which is a combustible body, and the whole mass instantly bursts into flame.

10. The "air-burner," which is of such value in the laboratory, owes its advantage to this principle. It consists of a cylindrical metal chimney, covered at the top with a piece of rather coarse iron wire gauze. This is supported over an Argand burner in such a manner that the gas may mix in the chimney with an amount of air sufficient to burn the carbon and hydrogen simultaneously, so that there may be no separation of carbon in the flame with consequent deposition of soot. The flame, being unable to pass through the wire gauze, burns in a steady, nearly invisible manner above.