LECTURE IV

HYDROGEN IN THE CANDLE-BURNS INTO WATER-THE OTHER PART OF WATER-OXYGEN

I SEE you are not tired of the candle yet, or I am sure you would not be interested in the subject in the way you are. When our candle was burning we found it produced water exactly like the water we have around us; and by farther examination of this water we found in it that curious body, hydrogen-that light substance of which there is some in this jar. We afterward saw the burning powers of that hydrogen, and that it produced water. And I think I introduced to your notice an apparatus which I very briefly said was an arrangement of chemical force, or power, or energy, so adjusted as to convey its power to us in these wires; and I said I should use that force to pull the water to pieces, to see what else there was in the water besides hydrogen; because, you remember, when we passed the water through the iron tube, we by no means got the weight of water back which we put in in the form of steam, though we had a very large quantity of gas evolved. We have now to see what is the other substance present. That you may understand the character and use of this instrument, let us make an i. experiment or two. Let us put together, first of all, some substances, knowing what they are, and then see what that instrument does to them. There is some copper (observe the various changes which it can undergo), and here is some nitric acid, and you will find that this, being a strong chemical agent, will act very powerfully when I add it to the copper. It is now sending forth a beautiful red vapor; but as we do not want that vapor, Mr. Anderson will hold it near the chimney for a short time, that we may have the use and beauty of the experiment without the annoyance. The copper, which I have put into the flask will dissolve it: it will change the acid and the water into a blue fluid containing copper and other things, and I purpose then showing you how this voltaic battery deals with it; and in the mean time we will arrange another kind of experiment for you to see what power it has. This is a substance which is to us like water-that is to say, it contains bodies which we do not know of as yet, as water contains a body which we do not know as yet. Now this solution of a salt (15) I will put upon paper, and spread about, and apply the power of the battery to it, and observe what will happen. Three or four important things will happen which we shall take advantage of. I place this wetted paper upon a sheet of tin foil, which is convenient for keeping all clean, and also for the advantageous application of the power; and this solution, you see, is not at all affected by being put upon the paper or tin foil, nor by any thing else I have brought in contact with it yet, and which, therefore, is free to us to use as regards that instrument. But first let us see that our instrument is in order. Here are our wires. Let us see whether it is in the state in which it was last time. We can soon tell. As yet, when I bring them together, we have no power, because the conveyers-what we call the electrodes-the passages or ways for the electricity-are stopped; but now Mr. Anderson by that [referring to a sudden flash at the ends of the wires] has given me a telegram to say that it is ready. Before I begin our experiment I will get Mr. Anderson to break contact again at the battery behind me, and we will put a platinum wire across to connect the poles, and then if I find I can ignite a pretty good length of this wire we shall be safe in our experiment. Now you will see the power. [The connection was established, and the intermediate wire became red-hot.] There is the power running beautifully through the wire, which I have made thin on purpose to show you that we have those powerful forces; and now, having that power, we will proceed with it to the examination of water. I have here two pieces of platinum, and if I lay them down upon this piece of paper [the moistened paper on the tin foil you will see no action; and if I take them up there is no change that you can see, but the arrangement remains just as it was before. But, now, see what happens: if I take these two poles and put either one or the other of them down separately on the platinum plates, they do nothing for me; both are perfectly without action; but if I let them both be in contact at the same moment, see what happens [a brown spot appeared under each pole of the battery]. Look here at the effect that takes place, and see how I have pulled something apart from the white-something brown; and I have no doubt, if I were to arrange it thus, and were to put one of the poles to the tin foil on the other side of the paper-why, I get such a beautiful action upon the paper that I am going to see whether I can not write with it-a telegram, if you please. [The lecturer here traced the word "juvenile" on the paper with one of the terminal wires.] See there how beautifully we can get our results! You see we have here drawn something which we have not known about before out of this solution. Let us now take that flask from Mr. Anderson's hands, and see what we can draw out of that. This, you know, is a liquid which we have just made up from copper and nitric acid while our other experiments were in hand; and though I am making this experiment very hastily, and may bungle a little, yet I prefer to let you see what I do rather than pre- pare it beforehand. Now see what happens. These two platinum plates are the two ends (or I will make them so immediately) of this apparatus; and I am about to put them in contact with that solution, just as we did a moment ago on the paper. It does not matter to us whether the solution be on the paper or whether it be in the jar, so long as we bring the ends of the apparatus to it. If I put the two platinums in by themselves they come out as clean and as white as they go in [inserting them into the fluid without connecting them with the battery] ; but when we take the power and lay that on [the platinums were connected with the battery and again dipped into the solution], this, you see [exhibiting one of the platinums], is at once turned into copper, as it were; it has become like a plate of copper; and that [exhibiting the other piece of platinum] has come out quite clean. If I take this coppered piece and change sides, the copper will leave the right-hand side and come over to the left side; what was before the coppered plate comes out clean, and the plate which was clean comes out coated with copper; and thus you see that the same copper we put into this solution we can also take out of it by means of this instrument. Putting that solution aside, let us now see what effect this instrument will have upon water (FIG. 73) Here are two little platinum plates which I intend to make the ends of the battery, and this (C) is a little vessel so shaped as to enable me to take it to pieces, and show you its construction. In these two cups (A and B) I pour mercury, which touches the ends of the wires connected with the platinum plates. In the vessel (C) I pour some water containing a little acid (but which is put in only for the purpose of facilitating the action; it undergoes no change in the process), and connected with the top of the vessel is a bent glass tube (D), which may remind you of the pipe which was connected with the gun barrel in our furnace experiment, and which now passes under the jar (F). I have now adjusted this apparatus, and we will proceed to affect the water in some way or other. In the other case I sent the water through a tube which was made red-hot; I am now going to pass the electricity through the contents of this vessel. Perhaps I may boil the water; if I do boil the water, I shall get steam; and you know that steam condenses when it gets cold, and you will there- fore see by that whether I do boil the water or not. Perhaps, how- ever, I shall not boil the water, but produce some other effect. You shall have the experiment and see. There is one wire which I will put to this side (A), and here is the other wire which I will put to the other side (B), and you will soon see whether any disturbance takes place. Here it is seeming to boil up famously; but does it boil? Let us see whether that which goes out is steam or not. I think you will soon see the jar (F) will be filled with vapor, if that which rises from the water is steam. But can it be steam? Why, certainly not; because there it remains, you see, unchanged. There it is standing over the water, and it can not therefore be steam, but must be a permanent gas of some sort. What is it? Is it hydrogen? Is it anything else? Well, we will examine it. If it is hydrogen it will burn. [The lecturer then ignited a portion of the gas collected, which burnt with an explosion.] It is certainly something combustible, but not combustible in the way that hydrogen is. Hydrogen would not have given you that noise; but the color of that light, when the thing did burn, was like that of hydrogen; it will, however, burn without contact with the air. That is why I have chosen this other form of apparatus, for the purpose of pointing out to you what are the particular circumstances of this experiment. In place of an open vessel, I have taken one that is closed (our battery is so beautifully active that we are even boiling the mercury, and getting all things right-not wrong, but vigorously right); and I am going to show you that that gas, whatever it may be, can burn without air, and in that respect differs from a candle, which can not burn without the air. And our manner of doing this is as follows: I have here a glass vessel (G) which is fitted with two platinum wires (I K) through which I can apply electricity; and we can put the vessel on the air pump and exhaust the air; and when we have taken the air out we can bring it here and fasten it on to this jar (F), and let into the vessel that gas which was formed by the action of the voltaic battery upon the water, and which we have produced by changing the water into it; for I may go as far as this, and say We have really, by that experiment, changed the water into that gas. We have not only altered its condition, but we have changed it really and truly into that gaseous substance, and all the water is there which was decomposed by the experiment. As I screw this vessel (G H) on here (H), and make the .tubes well connected, and when I open the stop-cocks (H H H), if you watch the level of the water(in F), you will see that the gas will rise. I will now close the stop-cocks, as I have drawn up as much as the vessel can hold, and being safely conveyed into that chamber, I will pass into it an electric spark from this Leyden jar (L), when the vessel, which is now quite clear and bright, will become dim. There will be no sound, for the vessel is strong enough to confine the explosion. [A spark was then passed through the jar, when the explosive mixture was ignited.] Did you see that brilliant light? If I again screw the vessel on to the jar, and open these stop-cocks, you will see that the gas will rise a second time. [The stop-cocks were then opened.] Those gases [referring to the gases first collected in the jar, and which had just been ignited by the electric spark] have disappeared, as you see; their place is vacant, and fresh gas has gone in. Water has been formed from them; and if we repeat our operation [repeating the last experiment], I shall have another vacancy, as you will see by the water rising. I always have an empty vessel after the explosion, because the vapor or gas into which that water has been resolved by the battery explodes under the influence of the spark, and changes into water; and by-and-by you will see in this upper vessel some drops of water trickling down the sides and collecting at the bottom. We are here dealing with water entirely, without reference to the atmosphere. The water of the candle had the atmosphere helping to produce it; but in this way it can be produced independently of the air. Water, therefore, ought to contain that other substance which the candle takes from the air, and which, combining with the hydrogen, produces water. Just now you saw that one end of this battery took hold of the copper, extracting it from the vessel which contained the blue solution. It was effected by this wire; and surely we may say, if the battery has such power with a metallic solution which we made and unmade, may we not find that it is possible to split asunder the component parts of the water, and put them into this place and that place? Suppose I take the poles-the metallic ends of this battery- and see what will happen with the water in this apparatus (FIG. 74), where we have separated the two ends far apart. I place one here (at A), and the other there (at B); and I have little shelves with holes which I can put upon each pole, and so arrange them that whatever escapes from the two ends of the battery will appear as separate gases; for you saw that the water did not become vaporous, but gaseous. The wires are now in perfect and proper connection with the vessel containing the water, and you see the bubbles rising; let us collect these bubbles and see what they are. Here is a glass cylinder (O); I fill it with water and put it over one end (A) of the pile, and I will take another (H), and put it over the other end (B) of the pile. And so now we have a double apparatus, with both places delivering gas. Both these jars will fill with gas. There they go, that to the right (H) filling very rapidly; the one to the left (O) filling not so rapidly; and, though I have allowed some bubbles to escape, yet still FIG. 74 the action is going on pretty regularly; and were it not that one is rather smaller than the other, you would see that I should have twice as much in this (H) as I have in that (O). Both these gases are colorless; they stand over the water without condensing; they are alike in all things-I mean in all apparent things; and we have here an opportunity of examining these bodies and ascertaining what they are. Their bulk is large, and we can easily apply experiments to them. I will take this jar (H) first, and will ask you to be prepared to recognize hydrogen. Think of all its qualities-the light gas which stood well in inverted vessels, burning with a pale flame at the mouth of the jar, and see whether this gas does not satisfy all these conditions. If it be hydrogen it will remain here while I hold this jar inverted. [A light was then applied, when the hydrogen burnt.] What is there now in the other jar? You know that the two together made an explosive mixture. But what can this be which we find as the other constituent in water, and which must therefore be that substance which made the hydrogen burn? We know that the water we put into the vessel consisted of the two things together. We find one of these is hydrogen: what must that other be which was in the water before the experiment, and which we now have by itself? I am about to put this lighted splinter of wood into the gas. The gas itself will not burn, but it will make the splinter of wood burn. [The lecturer ignited the end of the wood and introduced it into the jar of gas.] See how it invigorates the combustion of the wood, and how it makes it burn far better than the air would make it burn; and now you see by itself that every other substance which is contained in the water, and which, when the water was formed by the burning of the candle, must have been taken from the atmosphere. What shall we call it, A, B, or C? Let us call it O-call it "Oxygen"; it is a very good, distinct-sounding name. This, then, is the oxygen which was present in the water, forming so large a part of it. We shall now begin to understand more clearly our experiments and researches, because when we have examined these things once or twice we shall soon see why a candle burns in the air. When we have in this/way analyzed the water-that is to say, separated or electrolyzed its parts out of it, we get two volumes of hydrogen and one of the body that burns it. And these two are represented to us on the following diagram, with their weights also stated; and we shall find that the oxygen is a very heavy body by comparison with the hydrogen. It is the other element in water.

1 hydrogen	8 oxygen

9

Oxygen ………. 88.9
Hydrogen …….. 11.1

Water ………… 100.0

I had better, perhaps, tell you now how we get this oxygen abundantly, having shown you how we can separate it from the water. Oxygen, as you will immediately imagine, exists in the atmosphere; for how should the candle burn to produce water without it? Such a thing would be absolutely impossible, and chemically impossible, without oxygen. Can we get it from the air? Well, there are some very complicated and difficult processes by which we can get it from the air; but we have better processes. There is a substance called the black oxide of manganese; it is a very black-looking mineral, but very useful, and when made red-hot it gives out oxygen. Here is an iron bottle which has had some of this substance put into it, and there is a tube fixed to it (FIG. 75), and a fire ready made, and Mr. Anderson will put that retort into the fire, for it is made of iron, and can stand the heat. Here is a salt called chlorate of potassa, which is now made in large quantities for bleaching, and chemical and medical uses, and for pyratechnic and other purposes. I will take some and mix it with some of the oxide of manganese (oxide of copper, or oxide of iron would do as well); and if I put these together in a retort, far less than a red heat is sufficient to evolve this oxygen from the mixture. I am not preparing to make much, because we only want sufficient for our experiments; only, as you will see immediately, if I use too small a charge, the first portion of the gas will be mixed with the air already in the retort, and I should be obliged to sacrifice the first portion of the gas because it would be so much diluted with air; the first portion must therefore be thrown away. You will find in this case that a common spirit lamp is quite sufficient for me to get the oxygen, and so we shall have two processes going on for its preparation. See how freely the gas is coming over from that small portion of the mixture. We will examine it and see what are its properties. Now in this way we are producing, as you will observe, a gas just like the one we had in the experiment with the battery, transparent, undissolved by water, and presenting the ordinary visible properties of the atmosphere. (As this first jar contains the air, together with the first portions of the oxygen set free during the preparation, we will carry it out of the way, and be prepared to make our experiments in a regular, dignified manner.) And inasmuch as that power of making wood, wax, or other things burn, was so marked in the oxygen we obtained by means of the voltaic battery from water, we may expect to find the same property here. We will try it. You see there is the combustion of a lighted taper in air, and here is its combustion in this gas [lowering the taper into the jar]. See how brightly and how beautifully it burns! You can also see more than this: you will perceive it is a heavy gas, while the hydrogen would go up like a balloon, or even faster than a balloon, when not encumbered with the weight of the envelope. You may easily see that although we obtained from water twice as much in volume of the hydrogen as of oxygen, it does not follow that we have twice as much in weight, because one is heavy and the other a very light gas. We have means of weighing gases or air; but, without stopping to explain that, let me just tell you what their respective weights are. The weight of a pint of hydrogen is three-quarters of a grain; the weight of the same quantity of oxygen is nearly twelve grains. This is a very great difference. The weight of a cubic foot of hydrogen is one-twelfth of an ounce; and the weight of a cubic foot of oxygen is one ounce and a third. And so on we might come to masses of matter which may be weighed in the balance, and which we can take account of as to hundred-weights and as to tons, as you will see almost immediately. Now, as regards this very property of oxygen supporting combustion, which we may compare to air, I will take a piece of candle to show it you in a rough way- and the result will be rough. There is our candle burning in the air: how will it burn in oxygen? FIG. 76. I have here a jar of this gas, and I am about to put it over the candle for you to compare the action of this gas with that of the air. Why, look at it; it looks something like the light you saw at the poles of the voltaic battery. Think how vigorous that action must be. And yet, during all that action, nothing more is produced than what is produced by the burning of the candle in air. We have the same production of water, and the same phenomena exactly, when we use this gas instead of air, as we have when the candle is burnt in air. But now we have got a knowledge of this new substance, we can look at it a little more distinctly, in order to satisfy ourselves that we have got a good general understanding of this part of the product of a candle. It is wonderful how great the supporting powers of this substance are as regards combustion. For instance, here is a lamp which, simple though it be, is the original, I may say, of a great variety of lamps which are constructed for divers purposes-for lighthouses, microscopic illuminations, and other uses; and if it was proposed to make it burn very brightly, you would say, "If a candle burnt better in oxygen, will not a lamp do the same?" Why, it will do so. Mr. Anderson will give me a tube coming from our oxygen reservoir, and I am about to apply it to this flame, which I will previously make burn badly on purpose. There comes the oxygen: what a combustion that makes! But if I shut it off, what becomes of the lamp? [The flow of oxygen was stopped, and the lamp relapsed to its former dimness.] It is wonderful how, by means of oxygen, we get combustion accelerated. But it does not affect merely the combustion of hydrogen, or carbon, or the candle, but it exalts all combustions of the common kind. We will take one which relates to iron, for instance, as you have already seen iron burn a little in the atmosphere. Here is a jar of oxygen, and this is a piece of iron wire; but if it were a bar as thick as my wrist, it would burn the same. I first attach a little piece of wood to the iron; I then set the wood on fire, and let them both down together into the jar (FIG. 77). The wood is now alight, and there it burns as wood should burn in oxygen; but it will soon communicate its combustion to the iron. The iron is now burning brilliantly, and will continue so for a long time. As long as we supply oxygen, so long can we carryon the combustion of the iron, until the latter is consumed. We will now put that on one side, and take some other substance; but we must limit our experiments, for we have not time to spare for all the illustrations you would have a right to if we had more time. We will take a piece of sulphur: you know how sulphur burns in the air; well, we put it into the oxygen, and you will see that whatever can burn in air can burn with a far greater intensity in oxygen, leading you to think that perhaps the atmosphere itself owes all its power of combustion to this gas. FIG. 78. The sulphur is now burning very quietly in the oxygen; but you can not for a moment mistake the very high and increased action which takes place when it is so burnt, instead of being burnt merely in common air. I am now about to show you the combustion of another substance-phosphorus. I can do it better for you here than you can do it at home. This is a very combustible substance; and if it be so combustible in air, what might you expect it would be in oxygen? I am about to show it to you not in its fullest intensity, for if I did so we should almost blow the apparatus up; I may even now crack the jar, though I do not want to break things carelessly. You see how it burns in the air. But what a glorious light it gives out when I introduce it into oxygen! [Introducing the lighted phosphorus into the jar of oxygen.] There you see the solid particles going off which cause that combustion to be so brilliantly luminous. Thus far we have tested this power of oxygen, and the high combustion it produces, by means of other substances. We must now, for a little while longer, look at it as respects the hydrogen. You know, when we allowed the oxygen and the hydrogen derived from the water to mix and burn together, we had a little explosion. You remember also that when I burnt the oxygen and the hydrogen in a jet together, we got very little light, but great heat; I am now about to set fire to oxygen and hydrogen mixed in the proportion in which they occur in water. Here is a vessel containing one volume of oxygen and two volumes of hydrogen. This mixture is exactly of the same nature as the gas we just now obtained from the voltaic battery; it would be far too much to burn at once; I have therefore arranged to blow soap bubbles with it and burn those bubbles, that we may see by a general experiment or two how this oxygen supports the combustion of the hydrogen. First of all, we will see whether we can blow a bubble. Well, there goes the gas [causing it to issue through a tobacco-pipe into some soapsuds]. Here I have a bubble. I am receiving them on my hand, and you will perhaps think I am acting oddly in this experiment, but it is to show you that we must not always trust to noise and sounds, but rather to real facts. [Exploding a bubble on .the palm of his hand.] I am afraid to fire a bubble from the end of the pipe, because the explosion would pass up into the jar and blow it to pieces. This oxygen, then, will unite with the hydrogen, as you see by the phenomena, and hear by the sound, with the utmost readiness of action, and all its powers are then taken up in its neutralization of the qualities of the hydrogen. So now I think you will perceive the whole history of water with reference to oxygen and the air from what we have before said. Why does a piece of potassium decompose water? Because it finds oxygen in the water. What is set free when I put it in the water, as I am about to do again? It sets free hydrogen, and the hydrogen burns; but the potassium itself combines with oxygen; and this piece of potassium, in taking the water apart-the water, you may say, derived from the combustion of the candle-takes away the oxygen which the candle took from the air, and so sets the hydrogen free; and even if I take a piece of ice, and put a piece of potassium upon it, the beautiful affinities by which the oxygen and the hydrogen are related are such that the ice will absolutely set fire to the potassium. I show this to you today, in order to enlarge your ideas of these things, and that you may see how greatly results are modified by circumstances. There is the potassium on the ice, producing a sort of volcanic action. It will be my place when next we meet, having pointed out these anomalous actions, to show you that none of these extra and strange effects are met with by us-that none of these strange and injurious actions take place when we are burning, not merely a candle, but gas in our streets, or fuel in our fireplaces, so long as we confine ourselves within the laws that Nature has made for our guidance.

15 A solution of acetate of lead submitted to the action of the voltaic current yields lead at the negative pole, and brown peroxide of lead at the positive pole. A solution of nitrate of silver, under the same circumstances, yields silver at the negative pole, and peroxide of silver at the positive pole.