does—or, indeed, better—for, absolutely, that piece of lead will act at once upon the oxygen as the copper did in the other vessel with regard to the chlorine. And here, also, a piece of iron; if I light it and put it into the oxygen, it will burn away just as the carbon did. And I will take some lead, and show you that it will burn in the common atmospheric oxygen at the ordinary temperature. These are the lumps of lead which you remember we had the other day—the two pieces which clung together. Now these pieces, if I take them to-day and press them together, will not stick, and the reason is that they have attracted from the atmosphere a part of the oxygen there present, and have become coated as with a varnish by the oxyd of lead, which is formed on the surface by a real process of combustion or combination. There you see the iron burning very well in oxygen; and I will tell you the reason why those scissors and that lead do not take fire while they are lying on the table. Here the lead is in a lump, and the coating of oxyd remains on its surface, while there you see the melted oxyd is clearing itself off from the iron, and allowing more and more to go on burning. In this case, however [holding up a small glass tube containing lead pyrophorus], the lead has been very carefully produced in fine powder and put into a glass tube and hermetically sealed, so as to preserve it, and I expect you will see it take fire at once. This has been made about a month ago, and has thus had time to sink down to its normal temperature; what you see, therefore, is the result of chemical affinity alone. [The tube was broken at the end and the lead poured out on a piece of paper, whereupon it immediately took fire.] Look! look at the lead burning!—why, it has set fire to the paper! Now that is nothing more than the common affinity always existing between very clean lead and the atmospheric oxygen; and the reason why this iron does not burn until it is made red hot, is because it has got a coating of oxyd about it which stops the action of the oxygen—putting a varnish, as it were, upon its surface as we varnish a picture—absolutely forming a substance which prevents the natural chemical affinity between the bodies from acting.

I must now take you a little farther in this kind of illustration (or consideration, I would rather call it) of chemical affinity. This attraction between different particles exists, also, most curiously in cases where they are previously combined with other substances. Here is a little chlorate of potash containing the oxygen which we found yesterday could be procured from it; it contains the oxygen there combined and held down by its chemical affinity with other things, but still it can combine with sugar, as you saw. This affinity can thus act *across* substances, and I want you to see how curiously what we call combustion acts with respect to this force of chemical affinity. If I take a piece of phosphorus and set fire to it, and then place a jar of air over the phosphorus, you see the combustion which we are having there on account of chemical affinity (combustion being in all cases the result of chemical affinity). The phosphorus is escaping in that vapor, which will condense into a snow-like mass at the close of the lecture. But suppose I limit the atmosphere, what then? Why, even the phosphorus will go out. Here is a piece of camphor which will burn very well in the atmosphere—and even on water it will float about and burn, by reason of some of its particles gaining access to the air. But if I limit the quantity of air by placing a jar over it, as I am now doing, you will soon find the camphor will go out. Well, why does it go out?—not for want of air, for there is plenty of air remaining in the jar. Perhaps you will be shrewd enough to say for want of oxygen.

This, therefore, leads us to the inquiry as to whether oxygen can do more than a certain amount of work. The oxygen there (Fig. 30) cannot go on burning an unlimited quantity of candle, for that has gone out, as you see; and its amount of chemical attraction or affinity is just as strikingly limited; it can no more be fallen short of or exceeded than can the attraction of gravitation. You might as soon attempt to destroy gravitation or weight, or all things that exist, as to destroy the exact amount of force exerted by this oxygen. And when I pointed out to you that eight by weight of oxygen to one by weight of hydrogen went to form water, I meant this, that neither of them would combine in different proportions with the other, for you cannot get ten of hydrogen to combine with six of oxygen, or ten of oxygen to combine with six of hydrogen; it must be eight of oxygen and one of hydrogen. Now, suppose I limit the action in this way: this piece of cotton wool burns, as you see, very well in the atmosphere; and I have known of cases of cotton mills being fired as if with gunpowder through the very finely divided particles of cotton being diffused through the atmosphere in the mill, when it has sometimes happened that a flame has caught these raised particles, and it has run from one end of the mill to the other and blown it up. That, then, is on account of the affinity which the cotton has for the oxygen; but suppose I set fire to this piece of cotton which is rolled up tightly; it does not go on burning because I have limited the supply of oxygen, and the inside is prevented from having access to the oxygen just as it was in the case of the lead by the oxyd. But here is some cotton which has been imbued with oxygen in a certain manner. I need not trouble you now with the way it is prepared; it is called *gun cotton*. See how that burns [setting fire to a piece]; it is very different from the other, because the oxygen which must be present in its proper amount is put there beforehand. And I have here some pieces of paper which are prepared like the gun cotton, and imbued with bodies containing oxygen. Here is some which has been soaked in nitrate of strontia; you will see the beautiful red color of its flame; and here is another which I think contains baryta, which gives that fine green light; and I have here some more which has been soaked in nitrate of copper: it does not burn quite so brightly, but still very beautifully. In all these cases the combustion goes on independent of the oxygen of the atmosphere. And here we have some gunpowder put into a case, in order to show that it is capable of burning under water. You know that we put it into a gun, shutting off the atmosphere with shot, and yet the oxygen which it contains supplies the particles with that without which chemical action could not proceed. Now, I have a vessel of water here, and am going to make the experiment of putting this fuse under the water, and you will see whether that water can extinguish it; here it is burning out of the water, and there it is burning under the water; and so it will continue until exhausted, and all by reason of the requisite amount of oxygen being contained within the substance. It is by this kind of attraction of the different particles one to the other that we are enabled to trace the laws of chemical affinity and the wonderful variety of the exertions of these laws.

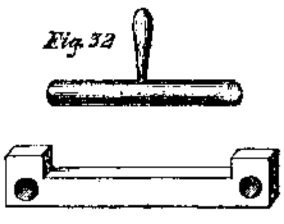
Now I want you to observe that one great exertion of this power which is known as *chemical affinity* is to produce HEAT and light: you know, as a matter of fact, no doubt, that when bodies burn they give out heat; but it is a curious thing that this heat does not continue—the heat goes away as soon as the action stops, and you see, thereby, that it depends upon the action during the time it is going on. It is not so with gravitation; this force is continuous, and is just as effective in making that lead press on the table as it was when it first fell there. Nothing occurs there which disappears when the action of falling is over; the pressure is upon the table, and will remain there until the lead is removed; whereas, in the action of chemical affinity to give light and heat, they go away immediately after the action is over. This lamp *seems* to evolve heat and light continuously, but it is owing to a constant stream of air coming into it on all sides, and this work of producing light and heat by chemical affinity will subside as soon as the stream of air is interrupted. What, then, is this curious condition of heat? Why, it is the evolution of another power of matter—of a power new to us, and which we must consider as if it were now for the very first time brought under our notice. What is heat? We recognize heat by its power of liquefying solid bodies and vaporizing liquid bodies; by its power of setting in action, and very often overcoming, chemical affinity. Then how do we obtain heat? We obtain it in various ways; most abundantly by means of the chemical affinity we have just before been speaking about, but we can also obtain it in many other ways. Friction will produce heat. The Indians rub pieces of wood together until they make them hot enough to take fire; and such things have been known as two branches of a tree rubbing together so hard as to set the tree on fire. I do not suppose I shall set these two pieces of wood on fire by friction, but I can readily produce heat enough to ignite some phosphorus. [The lecturer here rubbed two pieces of cedar wood strongly against each other for a minute, and then placed on them a piece of phosphorus, which immediately took fire.] And if you take a smooth metal button stuck on a cork, and rub it on a piece of soft deal wood, you will make it so hot as to scorch wood and paper and burn a match.

I am now going to show you that we can obtain heat not by chemical affinity alone, but by the pressure of air. Suppose I take a pellet of cotton, and moisten it with a little ether and put it into a glass tube (Fig. 31), and then take a piston and press it down suddenly, I expect I shall be able to burn a little of that ether in the vessel. It wants a suddenness of pressure, or we shall not do what we require. [The piston was forcibly pressed down, when a flame, due to the combustion of the ether, was visible in the lower part of the syringe.] All we want is to get a little ether in vapor and give fresh air each time; and so we may go on again and again, getting heat enough by the compression of air to fire the ether vapor.

Fig. 31

This, then, I think, will be sufficient, accompanied with all you have previously seen, to show you how we procure heat. And now for the effects of this power. We need not consider many of them on the present occasion, because when you have seen its power of changing ice into water and water into steam, you have seen the two principal results of the application of heat. I want you now to see how it expands all bodies—all bodies but one, and that under limited circumstances. Mr. Anderson will hold a lamp under that retort, and you will see, the moment he does so, that the air will issue abundantly from the neck which is under water, because the heat which he applies to the air causes it to expand. And here is a brass rod (Fig. 32) which goes through that hole, and fits also accurately into this gage; but if I make it warm with this spirit lamp, it will only go in the gage or through the hole with difficulty; and if I were to put it into boiling water, it would not go through at all. Again: as soon as the heat escapes from bodies, they collapse; see how the air is contracting in the vessel now that Mr. Anderson has taken away his lamp; the stem of it is filling with water. Notice, too, now, that although I cannot get the tube through this hole or into the gage, the moment I cool it by dipping it into water it goes through with perfect facility, so that we have a perfect proof of this power of heat to contract and expand bodies.

Fig. 32



THEORETICAL ECONOMY OF THE AIR ENGINE.

The theory of the greater power derived from a given amount of heat by the air engine, than by the steam engine, may be thus briefly stated:—

1,170 degrees of heat imparted to one cubic inch of water will raise 15 lbs, 1,696 inches.

The specific gravity of water is 770, air being 1, consequently air of a weight equal to 1 cubic inch of water will measure 770 cubic inches.

Air at zero, Fah., has its bulk doubled by 493 degrees of heat, hence 1,170 degrees of heat imparted to 770 cubic inches of air will raise 15 lbs. 1,658 inches.

Now, the specific heat of air is 2,669, water being 1; hence, it takes but about one quarter the quantity of heat to impart the same number of degrees to air as it does to water, and as the work of a given number of degrees imparted is about the same, heat performs, in round numbers, four times the work when applied to air that it does when applied to water.

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THE London *Mechanics' Magazine* says:—"Inventors are without doubt a troublesome class (to government officers), but, nevertheless, it is to inventors that we owe this very remarkable production—the British empire! Take away the inventors from amongst us, and we should sink to the condition of the Chinese."