[Reprinted from "The Sanitary Journal for Scotland," 1st January, 1877.]

ON SOME OF THE CONSTITUENTS OF THE ATMOSPHERE.*

By J. FERGUSON, Esq., A.M.,
Professor of Chemistry, University of Glasgow.

[After a general introduction, in which was considered the nature of a chemical change, of a chemical element, and of a chemical test, the main subject of the lecture was proceeded with.]

1. In this world of matter, man's body, as a piece of matter, depends, for the proper discharge of its functions, on four things—food, water, air, and clothing. Be it much or little, without these, in their widest sense, human life cannot be maintained. Viewed materially, the body is a most complicated self-acting apparatus for performing certain operations, and in this apparatus chemical actions are going on constantly. Some of these are comparatively apparent and simple, others are very complex, and there are, doubtless, many of which we have at present no knowledge at all; so that, altogether, physiological or animal chemistry is the most difficult and complicated of all the divisions of the science.

2. Now, obviously, it is of the greatest, or as the newspapers would say, of vital importance—it is a matter of life or death—that every one who is to live and be of use to himself and the community should be supplied with the best of these four conditions of living above mentioned; meaning by best not the most costly, or the most ornamental, or the rarest, but those which best do the work for which they are intended,—namely, pure water, pure air, nutritious food, suitable clothing. Most persons have to be supplied with these, partly by their own labour, partly by that of others, to whom the constitution of society entrusts their production.

* Part of a Popular Lecture, in the City Hall, to the Young Men's Christian Association, Glasgow, Monday, [illegible] October, 1876. Some slight alterations have been necessary to make this lecture, which was never intended for print, rather more readable; but these have been as few as possible.

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It is thus that men engaged in trades and professions entrust to the farmers and others the labour of getting their food from the soil, and of supplying wool, silk, cotton, flax, to be made into clothing. In the case of food and clothing, there is a certain amount of preparation and labour necessary, but in the case of water and air it is different. These are the free gifts of Nature; but air is not only free, it is the freest of all, the primary and invariable condition of life.

3. Those requisites—food and clothing—which involve labour in their preparation, are not unfrequently altered in quality by the addition, accidental sometimes, sometimes intentional, of other substances, which, however good for their own purposes, are not fitted for that of supporting life, for which the requisites to which they have been added are primarily intended. These added substances are usually called *adulterations*. They were known to the ancients, they are known to foreign nations, they are not unknown in our own country; indeed, the adulterations of food come ever and anon prominently before the public. When the extent to which this mixture with foreign, and sometimes with very deleterious matter, is carried in food, in the materials of clothing, and—most cruelly—in drugs, is considered, there is little wonder that these corruptions of trade evoked the vehement denunciations of the Laureate in the poem he wrote before the Crimean war. I am not, however, going to speak of these. I turn to the gifts of Nature—water and air.

4. There is a word of such portentous significance that I avoid using it before a Glasgow audience; but I may explain that it expresses the used, dirty, and drainage water of a house, or a village, town, or city. There is a natural reluctance, quite apart from scientific knowledge, on the part of one man consuming or using again, in any way, the water which has been fouled by himself or by another. The reluctance may sometimes not be very strong, but, such as it is, it is a natural hindrance to disease; and the reluctance certainly increases with knowledge. I do not wish now, however, to trouble you with the much debated question of—the word cannot be avoided

—sewage. I have, therefore, air only to speak about.

5. Though the air is a material substance, and though it was reckoned one of the elements from the time of the Greek philosophers to the end of last century, it finds no place among the sixty-five modern chemical elements. It must, therefore, be either a mixture or a compound. From the middle till towards the end of last century, experiments were made to ascertain the composition of the air; and these were ultimately successful. On the first of August, 1774, Dr. Joseph Priestley made the discovery of a gas in which ordinary combustible bodies—a candle, or a piece of coal—burn much more brilliantly than in ordinary air.

This air or gas* is not distinguished by any colour, taste, or smell; but as soon as a burning body—a lighted taper, for instance—is put into it, the burning goes on much more rapidly. Bodies, too, which burn intensely in the air, do so to a still greater extent in this gas. Phosphorus, a very inflammable body, blazes when put alight into it.

As was to be expected, this gas attracted a great deal of attention; its properties and functions, especially in combustion, were minutely studied and discussed, and the products obtained were examined. Subsequently, the now accepted explanation of combustion was enunciated:—combustion, or burning, is due to the rapid combination of what is usually called the *combustible* body with this gas, which exists in, or forms part of, the atmosphere. To the gas was given the name *oxygen*. This candle, then, or the gas used for lighting this hall, is burning because the constituents of the candle and gas are combining with the oxygen in the air of the room.

6. Two questions now occur:—

(*a*.) What is in the air which prevents bodies burning so brilliantly as in pure oxygen?

With regard to this first question, it was shewn, so long ago as 1772, that the air contains a large amount of a gas in which burning bodies are extinguished. After a number of investigations

*In the course of the lecture the experiments described were actually shewn.

the properties of this gas also were ascertained, and the name *nitrogen* was given to it. Speaking roughly, then, the atmosphere, the gaseous ocean at the bottom of which we live, consists of two gases:—oxygen, active in combustion, and nitrogen, passive in combustion. The proportions are 21 volumes of oxygen and 79 of nitrogen in 100 volumes of air. The way to get the nitrogen is to withdraw the oxygen by some combustible body—most easily by phosphorus—and then we find that there remain about four-fifths of the original volume unabsorbed; and by this gas a burning candle is extinguished. The answer to the first question, therefore, is: Because the oxygen is diluted with about four times its bulk of a passive gas.

7. (*b.*) The second question is, What comes of the products of the combustion of coal gas, or of a candle? When phosphorus or magnesium burns, we see the product in the form of a white vapour or solid. But when a candle burns, nothing appears at all. The flame goes on steadily, the wax and wick gradually disappear, the candle is destroyed. Is it so really? The answer depends on the meaning we attach to the word "destroyed." The form of the candle is certainly destroyed, but the matter of the candle is still in existence; it has entered into other combinations, and the new forms are not visible. These new compounds result from the union of the oxygen in the atmosphere with the constituents of the candle. If the candle had been heated to redness in a close vessel, inflammable gases would have escaped; and after these were gone, a black coked residue would have been found, which consists chiefly of the chemical element carbon. Carbon, then, is said to be one of the chemical constituents of the candle; and when carbon itself, or a carbonaceous substance, is burned in the air, it combines with the oxygen, and forms the substance called *carbonic acid gas.*

8. Though this gas cannot be detected by looking at it, it is possessed of several noticeable properties notwithstanding. One of these is that it is absorbed by lime water, and gives with it a white solid substance, or precipitate, which is identical in composition with chalk or marble. This precipitate is a *test* for carbonic acid gas, and

I shall have to refer to it as such repeatedly. A second noticeable property is, that, when put into it, burning bodies are extinguished. This can be shewn by putting into a jar of the gas a burning candle, or a tuft of cotton or tow soaked in turpentine, and lighted. A third noticeable property is its great density as compared with that of air; it is half as heavy again. This can be illustrated by pouring the gas from one vessel to another; but, to render it obvious, either the test by lime water or by a burning candle must be employed; or by drawing up a glass full of it, as water can be drawn from a well; or by siphoning it from one vessel to another, and making it extinguish a set of burning candles.

9. The atmosphere which has been described above as consisting chiefly of oxygen and nitrogen, contains this gas also, but only to the very small extent of one part in 2500 of air, or 00·04 per cent. This small quantity does not affect the burning of a candle; but if lime water be exposed to the air for a short time, the formation of a white precipitate indicates the presence of this gas.

10. When a burning candle is put into a limited supply of air,—contained, for instance, in a glass jar covered with a glass plate,—it burns for a short time and then goes out; and that for two reasons: because the oxygen becomes exhausted, and because what is produced in the burning extinguishes the flame. To enable a candle or a fire to burn properly, there must be a draught; that is, fresh air must be constantly supplied, and the air contaminated with the burned products must be carried off.

11. This can be illustrated by means of a lamp or candle fixed in a box. When lighted it burns in the air; but it will continue to burn even when surrounded by a glass shade or funnel fixed tightly in a hole in the box, provided there be another aperture—which may also be fitted with a shade—by which air has access to the flame. In such an arrangement, two currents of air can be shewn to exist,—an upward current in the funnel from the lamp, and a current down the other funnel towards the lamp. The combustion of the

candle is, in this apparatus, very readily affected. If the access of air by the downcast funnel be diminished, the flame becomes notably less, and if it be stopped, the flame is extinguished; if oxygen be passed in, the flame burns more brightly; if carbonic acid gas, the flame will be readily put out. From this will be seen what is meant by a draught, and how dependent a burning candle is on the amount and the kind of air supplied it; if the air be shut off, or if the wrong air be given it, it goes out.

12. This remarkable gas was discovered last century in 1754, some years earlier than the other two, by Dr. Joseph Black, who was subsequently teacher of Chemistry in the University here. He was examining a familiar operation: the burning of limestone in a lime kiln. What takes place in this operation? The notion was that the limestone acquired some burning property or principle from the fire, which rendered it "caustic." Black at first believed in this view, but he soon found that the difference is caused not by something being absorbed, but by something being lost; that the limestone does not become caustic from the fire, but is converted into quick or caustic lime by the loss of a large quantity of gas, which, because it was found firmly combined in a solid body, like limestone, was called "fixed" air. This great discovery—it was great, not merely as the discovery of a new fact, but of a reason of a material phenomenon, and of a scientific method of investigation—was the starting-point of the discoveries in gases which took place last century; and if a precise origin could be ascribed to a historically progressive course of thought like the science of chemistry, if we could altogether ignore the past up to a particular time, it would be more correct to date the origin of modern chemistry from Black's thesis, than from any other single event. It is impossible for me, on the present occasion, to convey to you the clearness, the precision, the directness, with which Black takes up the points in establishing his view of the causticity of lime. It was opposed, of course, at the time; but after long discussion,—in which, however, Black took little or no part,—so convinced was he of his

accuracy, his explanation was finally adopted. Yet so modest was he, that in a letter he wrote to his teacher and friend, Dr. Cullen, he himself criticized his paper most severely, and expressed his willingness to have his experiments appropriated by others, "rather than make them public," unless Dr. Cullen approved of their publication. Fortunately they were published, and the highest encomiums were subsequently passed on Dr. Black. In a Review of Black's work, read to the Glasgow Philosophical Society,* it was said:—

"The more one considers this investigation of Black's, not only in itself, in its completeness and finish, so far as the view he wished to advance is concerned, but in its opening a new field of inquiry, and giving a model method which could be and was actually followed, the more one is impressed with Black's genius for inductive reasoning, with his insight into material nature, with, if one may so speak, his insinuating manner of asking Nature questions, and the kind readiness with which Nature answered him. . . . . One marked feature of it is its independence of all the current topics of the time. . . . . It was not a mere analysis of a mineral product, like what chemists were accustomed to make, nor did it contain an attempt at a theory which should embrace all chemical phenomena; it neither attacked nor defended Stahl's hypothesis, though it was composed when phlogiston prevailed. It dealt with none of the conspicuous chemical changes, such as combustion, upon which all the chemists tried to throw light. It was simply a matter-of-fact examination of a matter of fact."

Great attention was, subsequently, bestowed on this gas, because it is produced universally in the combustion of fuel, because of its wide distribution in limestone, chalk, and other rocks, in a great number of minerals, and of salts and artificial compounds, and also because the gas wells up in springs and fountains, and, copiously, from the soil itself. Its derivation from carbon and oxygen was ascertained, and the name of carbonic acid gas was given to it.

* 18th December, 1871.

13. Let me now turn to another subject in which air is of the first importance, and which may be introduced by an experiment described a hundred years ago by the Swedish chemist Scheele. When a vessel containing some blood is kept close for a few hours, the air which has been in contact with the blood extinguishes a candle, while the blood has acquired a brighter red colour. This action closely resembles that of keeping a piece of phosphorus in air, whereby the oxygen is absorbed, and only the nitrogen is left. It must not be forgotten, however, that carbonic acid gas will also extinguish a candle, and that as blood is an organic or carbonaceous substance, and is here in contact with air, carbonic acid gas may also be evolved. It is a fact that both actions do take place. Every one knows that when a vein is opened the blood which flows is of a dark colour, but by exposure to the air becomes red; whereas blood from an artery is bright red. This darkening of red blood can be shewn by leaving it in contact with carbonic acid gas. If, now, from a tube of such dark blood drops be allowed to fall slowly into a globe into which air or oxygen is passing, the blood issuing from an exit-tube attached to the globe will be of a bright red colour. If we were to suppose the tube of dark blood to represent a vein, and the exit-tube an artery, the intermediate globe, in which the contact with the oxygen has taken place, would represent the lungs, into which air is being constantly drawn, and out of which it is being constantly expelled.

14. What action takes place in the lungs? In brief, the blood is exposed to the air. If so, and if the chemical actions be similar to those in the apparatus described above, the air expelled from the lungs must be very different from that taken in, because oxygen will be partly retained by the blood, while a considerable quantity of carbonic acid gas will be given off.

15. To shew that this is the case the following experiments may be made:—By breathing or blowing into lime water a white precipitate is produced; air which has been breathed twice over extinguishes a candle; and if the breath be passed by the down-cast funnel of the apparatus mentioned in section 11, the burning candle will be sensibly affected.

It has been proved beyond all doubt that combustion forms part of respiration, that the blood is aerated in the lungs, and that carbonic acid gas is produced, which must be got rid of at every breath.

16. It might also be shewn that if an animal were to be shut up in a covered vessel, it would cease to breathe, for the very same reasons that a candle would cease to burn, namely, from using up the oxygen, and producing carbonic acid gas; or, if an animal were to be dropped into a vessel of carbonic acid gas it would die,* in the same way that the turpentine flame or the burning candle was extinguished (§ 8).

Just as a fire requires a draught of fresh air for combustion, so animals, man included, require a draught of fresh air for respiration.

17. To what conclusions do these facts point? There is a great outcry at the present time, and justly, against adulterated food and against polluted water; but we never hear a syllable about the pollution of the atmosphere; and yet, of the three, it is that which all men and animals are not only constantly using, but without which they cannot do for a single second. There are times for eating and drinking, but there are no times for breathing. We do not lay in a stock of breath, like a pneumatic car, to keep us going for so many hours. We are always breathing; always taking in air, or oxygen, and throwing out carbonic acid. Now, the proportions of this latter gas in inspired and expired air are remarkably different; for whereas in the former it amounts to only 0·04 per cent. of the volume, in the latter it is 4·33 per cent., or fully one hundred times as much. It has been pointed out that expired, or out-breathed, air is such that a candle cannot burn in it, and any one can find by trial how laborious and disagreeable it is to breathe the same air two or three times over. Indeed, if the operation were compelled to be repeated, the

* The effect of carbonic acid gas upon a dog is exhibited in the Grotto del Cane, in Italy. It is a hollow in the hill side, with a sloping floor, through which the gas passes up. Into the deepest part of the layer of gas a dog is placed, and when it is on the point of expiring it is lifted out and carried into the open air, where it gradually recovers. This cavern was known for its poisonous atmosphere in the time of the Romans.

performer would, in a brief time, die of suffocation.*

18. Air, then, which has been breathed, is like water which has been used till it has become unwholesome; but in the ordinary treatment of the two we encounter one of those singular anomalies of behaviour which man occasionally displays.

There are few who would relish the proposal to use the same water for washing until it could be used no longer. Still fewer would like the arrangement if the water were to be used by a dozen or a hundred others; and I believe that all would revolt from the idea of sharing it with a thousand or two of persons. Yet we do not hesitate to breathe over and over again the same air used already, not only by ourselves, but by almost any number of persons that can be brought together, without making the slightest provision for the constant and regular renewal of the air, and for the carrying away of the carbonic acid gas.

19. We make boxes, which we call rooms; we pile these boxes on the top of each other, and call the result houses. We pack the houses as close as we can together, and call the results streets or wynds, as the case may be; and the whole agglomeration of cells we call cities. Into these boxes or cells are put human beings, each of whom is producing, as the very condition of life, a quantity of suffocating carbonic acid gas. This gas, of course, goes into the air in the box or cell called a room; but to be breathed over again without inconvenience, it ought to be diluted with fresh air until it reaches the normal amount of 0·04 per cent. What provision is there in houses, or halls, or theatres, or churches, for constantly supplying fresh air to the extent necessary?—Absolutely none in general. If it be hurtful for one person to be compelled to breathe the same air repeatedly, and if there be difficulty in supplying him with fresh air, what must it be when there are hundreds of thousands of persons collected on

* This happened in a historical event, to which, however, allusion is now seldom made. On June 20, 1756, 146 British gentlemen, merchants and others in Calcutta, were seized by the nabob, and thrust into a dungeon, called the "Black Hole," about 18 feet square. In the morning 123 of the prisoners were dead; suffocated, by having been compelled to breathe the same air continuously.

a comparatively small area, consuming and contaminating the air, and how is the supply to be kept up?

This might be considered enough; but, to increase the difficulty and the danger, there is, besides, all the carbonic acid gas produced by the burning of fuel, and of gas, candles, and lamps, by fermentation, and by the decay of vegetable and animal matter.

The vast quantity of poisonous gas so produced must be got rid of, and fresh air must take its place, otherwise the inhabitants could not live. In ordinary circumstances, the renewal is effected by the wind and air currents, by rain and by diffusion, the property possessed by gases of mixing with each other. Suppose, however, a cessation of wind and a low temperature, which would cause the carbonic acid gas to accumulate in the city where it is produced, we should soon have evidence of its deleterious or even fatal influence. Nor is this altogether impossible. It is fresh in the recollection, how, a couple of years ago, when there was a stagnation in the atmosphere, when the city was enveloped in a dense fog, and the temperature was low, there was experienced great difficulty in breathing, and the mortality of the city rose greatly; how, in short, Glasgow became a sort of Black Hole of Scotland, just as, at the same time, London was another Black Hole, where cattle actually died of suffocation.

Much short of actual poisoning, however, we suffer from want of air. The best evidence on this point is the feeling of relief in passing from a close, crowded room, from a crowded hall or church, into the street even of a large town; and, still more markedly, the feeling of oppression and of disgust which seizes on one who passes from the open air into a crowded assembly.

Experiments have been made on the amount of carbonic acid gas in the air of theatres and other places after they have been occupied for a couple of hours, and the amount has always been found to be much higher than the normal, reaching sometimes to four and five, and even to eight times what it ought to be.

20. I have spoken chiefly of the contamination

of air by carbonic acid gas, because its production is unavoidable; but there are products, not so abundant, perhaps, but disagreeable and deleterious, which pollute the atmosphere of the city, destroy vegetation, blight the trees in the parks, and render respiration difficult. Sulphurous acid, sulphuric acid, sulphuretted hydrogen, hydrochloric acid, and other substances evolved in certain manufactures, may be viewed as refuse, a sort of gaseous sewage. And if it be wrong, a thing to be opposed, as is now the case, for the liquid refuse from a town or manufactory to pollute a river or a water supply, it is difficult to see how it can be right for what has just been called gaseous sewage to contaminate the pure air, the only thing, perhaps, that all men can claim indisputably as a birth-right, and the abuse of which is followed by the punishment inevitably entailed by all violated natural conditions.

21. If we wish, then, to have cleaner, healthier, and more beautiful towns, we must give more attention to the ventilation of our dwellings and large buildings, to the width of our streets, to the parks and free air spaces; we must take more heed not to throw into the atmosphere dirt which we can keep out of it, lest we should be punished by having to breathe it; we must see what can be done to remove from it the clouds of black smoke, which are disgraceful alike to science and to taste, and which cut off from us an appreciable part of the sun's influence. If, after all our trouble, the air of our cities will still be destitute of the purity of the air which is found among our own northern mountains, or of that with which the western wind bathes our Atlantic coasts, we shall at least have done what we could to make modern city life as pure, physically, as possible, and to remove from us the sin of self-destruction which the huge black canopy that floats above us directly and indirectly occasions.