XVII. *On the Changes produced in Atmospheric Air, and Oxygen Gas, by Respiration.* *By* W. Allen, *Esq. F. R. S. and* W. H. Pepys, *Esq. F. R. S.*

Read June 16th, 1808.

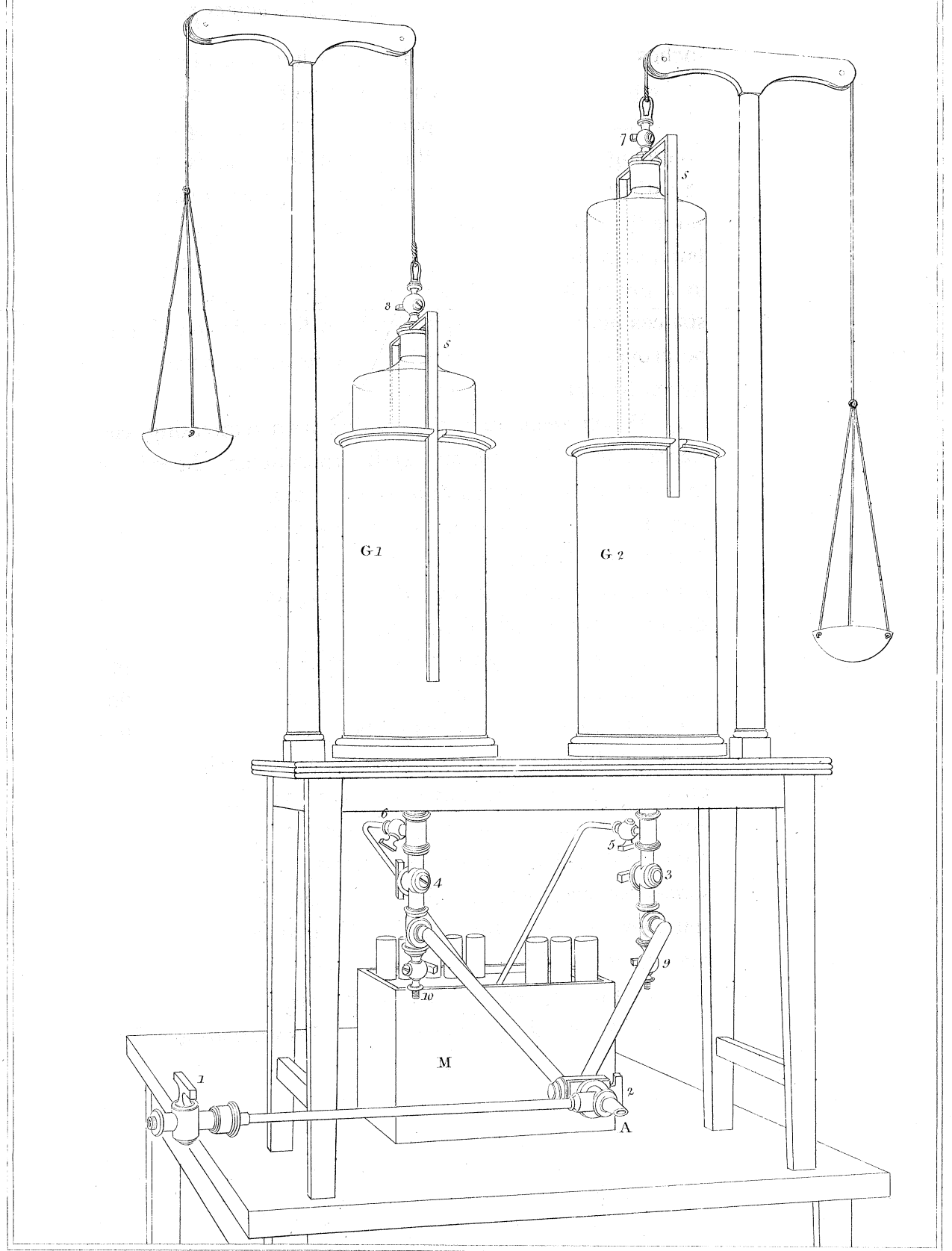
The process of respiration, or breathing, is so intimately connected with our existence in life, that from its first moments, to the final close, sleeping and waking, this necessary action is constantly maintained: nor can it be suspended even for a few minutes without considerable pain and the utmost danger. This important process has of course excited the curiosity both of ancient and modern philosophers; among the latter we find the distinguished names of Mayow, Priestley, Goodwin, Menzies, Spallanzani, Scheele, Lavoisier and Davy, whose successive labours have thrown great light upon this difficult subject, and prepared the way for farther investigation; but it is impossible to take a review of what has already been done, without perceiving that some important points were by no means satisfactorily settled; an accurate method of separating the different gasses, and ascertaining their exact proportion in any given mixture, was still a desideratum when many of the experiments were made, and it is only of late years that Eudiometry has attained its present perfection: the quantity of residual gas in the lungs after a forced expiration was a matter in dispute among former experimenters, some making it one hundred and nine cubic inches, and others only forty;

and yet it is of the utmost consequence in all calculations upon the effects produced, especially upon small portions of gas, that the state of the lungs should be accurately determined; this constitutes the great difficulty in the investigations. We therefore commenced our labours by constructing an apparatus, in which we are able to respire from three to four thousand cubic inches of gas, conceiving, that in this quantity, the error arising from the residual gas in the lungs must be so much obviated as to permit the most satisfactory results.

The apparatus consists of three gasometers, two of which are filled with mercury, and one with distilled water.

The water gasometer which belongs to the Royal Institution, is capable of holding four thousand two hundred cubic inches of gas, and each of the mercurial ones three hundred cubic inches: the apparatus was so arranged that the inspirations were all made from the water gasometer, and the expirations into the mercurial gasometers alternately. Each of the gasometers is furnished with a graduated scale, and they are all made to range with each other, so that the quantity of gas inspired and expired could be immediately and exactly ascertained: to each of the mercurial gasometers a glass tube is fixed, and made to enter a mercurial bath, from which portions of the expired air could at any time be taken for examination.

By the kindness of our friend SILVANUS BEVAN, we are enabled to give an accurate drawing of the apparatus.



Silvanus Bevan del. *Basire sc.*

Description.

Fig. 1. The communication with the water gasometer.

2. A cock so constructed that it might be made to communicate with either of the mercurial gasometers, while at the same time all connexion with the other was cut off.

A. The mouth piece.

Fig. 3. to 10. Brass cocks.

G. 1. and G. 2. Mercurial gasometers.

S. S. Scales graduated to cubic inches.

M. Mercurial bath.

The large reservoir or water gasometer is not shewn in this drawing, it having been so frequently described in chemical works.

Manner of conducting the Experiment.

Our first care was, to be certain that all the parts of our apparatus were perfectly air-tight, and this, from the nature of it, was very easily ascertained; we agreed that the breathing should always be performed by one of us, and the registering, &c. by the other, as each would by that means acquire a greater degree of dexterity in performing his part, and the results would be more uniform.

The water gasometer being filled with common air to a certain mark upon the scale, and the mercurial ones completely empty, the person to breathe, whom we shall uniformly call the operator, was seated upon a stool, with his mouth even with the tube A., his nose being secured with a steel clip. He made as complete an expiration as possible

into the open air, then applying his lips to the tube, and keeping his left hand constantly on the cock, fig. 1, and his right hand on the cock, fig. 2, he opened the communication with the water gasometer, and made an inspiration; then immediately closing it, he opened with his right hand the cock at 2; and that at 4 being also opened, he expired into the mercurial gasometer G. 1.; then closing 2, which cut off all communication with the mercurial gasometer, he opened 1, in order to make a fresh inspiration; then closing it, he again opened 2, and expired into the mercurial gasometer; and proceeding in this way, always taking care to shut one cock before the other was opened, the air was made to pass from the water gasometer, through the lungs of the operator into the mercurial gasometer, and this with great ease, as the diameters of the tubes were purposely made large. The scale of the mercurial gasometer was carefully noticed, and when nearly full, the cock 4 underneath was shut off: then, by a signal from the operator, his colleague opened 3, and the expirations were received in G. 2. While this was filling, the number of cubic inches in G. 1 was registered, a portion saved in the mercurial bath, and the rest quickly expelled. This operation was repeated until the contents of about twelve or thirteen mercurial gasometers were taken off; the operator always concluding with a strong effort to empty his lungs as completely as possible. The quantity inspired from the water gasometer was then compared with the quantities expired into the mercurial gasometers, and the difference noted. The following are the results of the first ten experiments.

No.	Time.	Cubic inches of common air Inspired.	Cubic Inches of Gas Expired.	Deficiency.
1.	time not noted	3760	3741	19
2.	11 minutes	3900	3869	31
3.	10½ ———	3624	3620	4
4.	10½ ———	3570	3550	20
5.	11 ———	3685	3653	32
6.	11 ———	3380	3355	25
7.	10½ ———	3180	3141	39
8.	10½ ———	3360	3298	62
9.	10½ ———	3290	3267	23
10.	11 ———	3580	3543	37

In this last experiment we ascertained that the expired gas contained 8 per cent. of carbonic acid.

The breathing in these cases was as nearly natural as we conceive it possible to be in any apparatus; the operator was scarcely fatigued, and his pulse not raised more than about one beat in a minute; the respirations however were deeper and fewer than natural, amounting only to about 58 in eleven minutes, whereas from repeated observations at different and distant times he makes 19 in a minute. The smallness of the deficiency surprised us very much, as, from the reports of other experimenters we had been prepared to expect a much greater loss. It might be objected that the air was rarefied by passing through the lungs; but this was almost immediately counteracted by the mass of quicksilver in the gasometers, which amounted at least to one hundred and fifty pounds; and we have repeatedly noticed, that air under these circumstances has suffered no perceptible diminution by standing for a considerable time; in one case, in which air from

the lungs was driven into the mercurial gasometers for twenty-seven minutes, the temperature of the quicksilver at the end of the experiment was not raised half a degree of FAHRENHEIT's thermometer. The deficiency, in our opinion, principally arises from the difficulty in bringing the lungs precisely to the same state after, as before the experiment; and it must be recollected that the operator commenced by a forcible expiration into the open air, but finished by a forcible expiration into the mercurial gasometer. Now, although this gasometer was counterpoised by weights in the scale attached to it, yet we can easily conceive that more resistance might be afforded to the complete evacuation in the latter case than in the former, and consequently the lungs might contain a few inches more after the experiment than before it, which might in some measure account for the deficiency.

In the eleventh experiment, portions of gas were taken off from each of the mercurial gasometers as they were filled, and these portions being afterwards mixed were carefully examined.

Eleventh Experiment.

Barom.	Thermom. Faht.	Time.	Cubic Inches of common air Inspired.	Cubic inches Expired.	Deficiency.
30,4	50°	11 min.	3460	3437	23

To prevent repetition, we shall here state that all the trials were made in the same manner, and with the same apparatus, namely, the Eudiometer, described in the Society's Transactions for 1807, in which one cubic inch is divided into one hundred parts; and that in almost every instance we made two, and sometimes three experiments on the same gas, and

derived fresh confidence from the remarkable coincidence and uniformity of the results. No precaution was at any time omitted which appeared to us necessary to insure accuracy.

One hundred parts of the expired gas being agitated with lime water in the eudiometer, the lime water became turbid, and 8.5 parts of the gas were absorbed, which were consequently carbonic acid; the remaining 91.5 parts were treated with the green sulphate of iron, saturated with nitrous gas, as recommended by Professor DAVY, and afterwards with the simple solution of the green sulphate, when 12.5 parts were absorbed, which were consequently oxygen, and the remaining 79 azote.

100 parts of the expired gas therefore consisted of

8.5 carbonic acid.
12.5 oxygen.
79. azote.

100

The air contained in the water gasometer, previous to the experiment, being examined by the same tests, consisted in 100 parts of

21 oxygen.
79 azote.

100

In trying common atmospheric air with lime water, we could never find any quantity of carbonic acid perceptible in the eudiometer of 100 parts.

Calculation for Carbonic Acid.

100 : 8.5 :: 3437 : 292.145.

So that 292.14 cubic inches of carbonic acid gas were given off in eleven minutes, or 26.55 cubic inches per minute, which is almost exactly the estimate of Professor DAVY.

In this experiment the operator inspired 3460 cubic inches in eleven minutes, and felt himself in a natural state when he left off. Then, as he makes usually under common circumstances nineteen respirations in a minute,

$$11 \times 19 = 209 \quad \frac{3460}{209} = 16.5$$

it follows, that he takes in $16\frac{1}{2}$ cubic inches at every easy inspiration.

As all the experiments had been hitherto made upon the lungs of one person, we concluded that the next should be performed upon our assistant.

Twelfth Experiment.

Barom.	Therm. Faht.	Time.	Cub. inches of common air Inspired.	Cubic Inches Expired.	Difference.
30.3	56°	$5\frac{1}{2}$ min.	3300	3311	11 increase

Here, as usual, the lungs were exhausted both before, and at the close of the experiment.

The excess of eleven cubic inches, in this case, no doubt arose from the person not having been in the habit of exhausting his lungs, so that they contained more when he began than when he left off; his lungs appeared to be of greater capacity than those of the usual operator.

Portions of gas were saved from each of the mercurial

gasometers as they were filled, which being mixed together, for the average gave the following results:

100 parts of the mixture contained

8.5 carbonic acid
12.5 oxygen.
79 azote.

100

Calculation for Carbonic Acid.

100 : 8.5 : : 3311 : 281.43.

Consequently 281,43 cubic inches of carbonic acid gas were given off in $5\frac{1}{2}$ minutes.

In this experiment we meet with a remarkable fact, viz. that as much carbonic acid gas was given off in $5\frac{1}{2}$ minutes, as in the former experiment in eleven minutes; so that it appears, whenever atmospheric air is taken into the lungs, it returns charged with about 8 per cent. carbonic acid. The faster respiration is performed, the more carbonic acid is given off, and consequently the more oxygen consumed: in this instance it was given off at the rate of fifty-one cubic inches per minute.

Thirteenth Experiment.

We now proceeded to carry on the respiration of common air for a much longer period than usual, and of course on a much larger quantity. The experiment was made by the same operator who had performed all the others, except the 12th. Eleven mercurial gasometers having been filled, taken off, and registered, the operator continued to breathe in the 12th until a mark was made by his colleague upon the scale

of the water gasometer, and it was again filled with common air to the usual division on the scale. This occupied but a very short space of time. The operator, without taking his lips from the tube, then filled twelve more of the mercurial gasometers, which were registered as before, and he continued to breathe in the 12th, until the water gasometer was again replenished; eleven more were then filled, and portions saved from each: the experiment was completed by a forcible expiration of 166 cubic inches into the 12th; and this last portion being left for an hour and a half was not perceptibly diminished in volume.

Barom.	Therm. Faht.	Time.	Cub. inches of common air inspired.	Cub. inches expired.	Deficiency.
29,85	68°	24′.37″	9890	9872	18

The breathing was so nearly natural that the operator was scarcely fatigued, and thought that he could have gone on for a much longer time.

The smallness of the deficiency, notwithstanding the experiments occupied $24\frac{1}{2}$ minutes, is a striking circumstance, and leads us to suspect still more strongly, that the deficiency principally arises from the impossibility of always bringing the lungs to the same state after forcible expiration.

100 parts of the mixture of expired gas gave

8 carbonic acid,
13 oxygen,
79 azote.

100

Calculation for Carbonic Acid.

100 : 8 : : 9872 : 789,76.

So that 789,76 cubic inches of carbonic acid gas were given off in 24½ minutes, which gives thirty-two cubic inches per minute. But here it must be noticed that the respiration was more rapid than in the 11th experiment, and a larger quantity of carbonic acid given off in the same time. This agrees with the 12th experiment.

We are very much inclined to think that, in ordinary respiration, a great part of the air is returned unaltered, viz. that contained in the fauces, in the trachea, and probably a portion of that in the larger branches of the bronchia. If this circumstance be not adverted to in experiments upon small quantities of air, the results can never be correct. There is even a considerable difference in the quality of the first and last portions of a single inspiration. In some experiments made with a view to this subject, a small quantity of the first portions, given off in a common and natural expiration, was received in a vessel over mercury; on examination, it only contained 3.5 per cent. carbonic acid; in other experiments the first portions contain from three to five per cent.; while the general average appears by the 11th, 12th, and 13th experiments, to be about eight.

The operator, after rather more than a natural inspiration, expired 204 cubic inches into the mercurial gasometer, making his utmost efforts to press as much as possible out of the lungs, this contained 9.5 per cent. of arbonic acid. Here we are to recollect, that these 204 cubic inches contained the first, as well as the last portions; the first portions have been

proved to contain only from three to five per cent.; consequently the last portions must contain more than appears by the average; that is, more than 9.5 per cent.

It now appeared to us of consequence to ascertain exactly what happened to a given volume of atmospheric air, when it was inspired and expired as often as possible.

*Fourteenth Experiment.**

Three hundred cubic inches of atmospheric air were admitted into the mercurial gasometer G. 1.; the other, G. 2, was empty. The nose being properly secured, and the mouth applied to the tube A, as usual, air was drawn from G. 1, and by half turning the cock, 2, was expired into G. 2. This was repeated until the contents of G. 1 had been made to pass through the lungs, and transmitted to G. 2. The air was then inspired from G. 2, and expired into G. 1, until G. 2 was nearly empty. This was repeated about eight or ten times during three minutes, until respiration became extremely laborious, and the operator desisted.

The whole 300 cubic inches must have passed eight or ten times through the lungs; and we confidently expected, that on examining the air we should have found an unusual proportion of carbonic acid.

But 100 parts gave only 9.5 carbonic acid
5.5 oxygen
85. azote.

100

* In this experiment there was obviously no occasion to make allowance for the air contained in the tubes and sockets. We find its volume to be eighteen cubic inches.

Here was an increase of six parts in 100 of something which the tests for oxygen would not take up, and also a loss of six per cent. oxygen. This seemed to convince us, that under certain circumstances, as during some peculiar alteration in the vital functions, gaseous oxide of carbon, carburetted hydrogen, or some other gas not absorbable by lime water or the tests for oxygen, might be given off from the lungs, and we accordingly determined to repeat CRUIKSHANK'S experiments with hyperoxygenised muriatic acid gas.

We procured the gas from hyperoxygenised muriate of potash by means of muriatic acid, and mixing it with a known portion of gaseous oxide of carbon in a flint stopper bottle, the mouth of which was immersed in mercury for twenty-four hours, the gaseous oxide of carbon was converted into carbonic acid gas, as was proved by its effects upon lime water, which, when both the gasses are pure, absorbs them entirely after they have remained together for twenty-four hours; it was plain, therefore, that we had the means of detecting gaseous oxide of carbon, and doubtless carburretted hydrogen, if any should be contained in the expired gas. From a conviction of the importance of these experiments we were determined to take nothing upon trust.

Fifteenth Experiment.

We repeated the 14th experiment with a little variation. In this case we employed only one of the mercurial gasometers, into which exactly 300 cubic inches of atmospheric air were admitted. The operator having made an easy expiration, applied his mouth to the cock at the top of the bell glass, and the time being noted, began to breathe; in less

than a minute he found himself obliged to take deeper and deeper inspirations; and at last the efforts of the lungs to take in air became so strong and sudden, that the glass was in some danger of being broken against the side of the gasometer. A great sense of oppression and suffocation was now felt in the chest, vision became indistinct, and after the second minute his whole attention seemed to be withdrawn from surrounding objects and fixed upon the experiment. He now experienced that buzz in the ears which is noticed in breathing nitrous oxide, and after the third minute had only sufficient recollection to close the cock after an expiration. This secured the result of the experiment; but he became so perfectly insensible that, on recovering, he was much surprised at finding his friend and the assistant on the table in the act of supporting him. It was noticed that he made thirty-five inspirations during the experiment. We now examined the air which had been so treated.

100 parts contained 10 carbonic acid,
4 oxygen,
86 azote,

100

In this experiment it is remarkable, that the air which had been so often through the lungs, should only have furnished 10 per cent. of carbonic acid, while the air which passes them but once contains from 8 to 8.5.

Here the oxygen had lost 7 from 21, and the azote had gained 7 upon 79.

We knew by previous experiment,* that every cubic inch of

* See the experiments on carbonic acid in the Society's Transactions.

carbonic acid gas required exactly a cubic inch of oxygen for its formation; the ten parts of carbonic acid may therefore be reckoned as oxygen, which would make the constitution of

the gas after the experiment { 14 oxygen, 86 azote,

whereas before the experiment it was { 21 oxygen, 79 azote.

Now we did not suppose the residuum of 86 to be all azote, though 79 might be; therefore seven parts appeared to have been added by this unnatural mode of respiring, and we conjectured the addition might be gaseous oxide of carbon.

To ascertain this, we put 40 parts into a flint stopper bottle, and nearly filled it with about 100 parts hyperoxygenised muriatic acid, procured as before, and recently prepared; the stopper being put in, over distilled water, we plunged it in quicksilver, and filled a second bottle in the same way, as a comparative experiment.

We next procured some pure azote, by absorbing the oxygen from a portion of atmospheric air by the saturated green sulphate and simple green sulphate as usual; 40 parts of this azote were mixed with the same proportion of the acid gas as in the other experiment, and the whole suffered to stand for forty-eight hours; at the end of this time the azote was examined, by washing it first in distilled water, and afterwards in the eudiometer with the tests for oxygen; and there were still exactly 40 parts left; proving that the hyperoxygenised muriatic acid gas has no action upon azote.

We then examined the bottles containing the residuum from the air that had been so often respired, and found that it had not experienced the slightest change; it was therefore plainly

azote; and on reflection, it occurred to us, that if a certain proportion of oxygen had been absorbed or lost in any way, while the azote remained unaltered, there must be an increased proportion of the latter.

Now we knew exactly both the bulk and the constitution of the air before the experiment; but it was impossible to know the bulk or volume after the experiment otherwise than by calculation.

The 300 cubic inches of atmospheric air before the experiment contained 21 oxygen, 79 azote in 100 parts, making the total quantity of oxygen 63 cubic inches,

azote 237

300

Now if the lungs be capable of fixing permanently any azote from the atmosphere, it appears by our experiments that the quantity must be very minute, seeing that in the 11th, 12th, and 13th experiment, it did not disturb the proportion of azote, as shewn by the eudiometer; we shall therefore in the present instance assume the volume of azote after the experiment at 237 cubic inches, as before.

But after the experiment, every 100 parts consisted of 86 parts azote, and 14 oxygen, either in the form of carbonic acid, or free.

$$86 : 14 :: 237 : 38.58.$$

Therefore the total quantity of oxygen left after the experiment would have been 38.58 cubic inches.

Then 237 azote + 38.58 oxygen = 275.58;

the quantity of gas after respiration would therefore have been 275.58 cubic inches.

300 — 275.58 = the loss of oxygen, or 24.42 cubic inches.

It appears, therefore, that 24.42 cubic inches of oxygen had been absorbed by the system under the circumstances of this experiment.

Reviewing the 14th experiment, it appears that the gas after respiration contained 85 per cent. azote, and 15 per cent. oxygen, either in the state of carbonic acid, or free.

State of the Air before the Experiment.

300 = 237 azote + 63 oxygen.

After the Experiment.

85 : 15 :: 237 : 41.82.

The total quantity of oxygen after the experiment appears to be 41.82 cubic inches.

Then 237 azote + 41.82 oxygen = 278.82.

The total volume after the experiment appears to be 278.82 cubic inches.

300 — 278.82 = 21.18.

The loss of oxygen in this case was 21.18 cubic inches.

We are disposed to consider the 11th as a standard experiment relative to carbonic acid gas, because the quantity of air respired in a given time is pretty near the average of the first ten experiments; and because it very nearly agrees with the statement of Professor DAVY. In this experiment 292 cubic inches of carbonic acid gas were given off in eleven minutes; the barometer was 30.4, the thermometer 50°, the volume being calculated at the mean, viz. barometer 30, thermometer 60°, will be 302 cubic inches given off in eleven minutes, or 39534 cubic inches in twenty-four hours, supposing the production to be uniform during all that period;

and as 100 cubic inches of carbonic acid gas weigh 47.26 grains,

100 : 47.26 :: 39534 : 18683.76;

the weight of the carbonic acid gas amounts to 18683.76 grains; and estimating the carbon in it at 28 parts in 100, according to LAVOISIER, or 28.60, as calculated in the experiments on diamond, recorded in the Society's Transactions.

100 : 28.60 :: 18683.76 : 5363.55 grains;

it will follow that 5363.55 grs. or above 11 oz. troy of solid carbon, are emitted by the lungs in the course of twenty-four hours; and that 39534 cubic inches of oxygen gas are consumed in the same time. But when we consider that in respiration perfectly natural, a much smaller quantity of air can come in contact with those parts of the lungs calculated to act upon it, the proportion of carbonic acid gas given off in natural respiration, ought probably to stand considerably lower than in the above estimate; but at all events it will be very considerable.

Sixteenth Experiment.

Having made so many experiments upon atmospheric air, we now proceeded to ascertain the effects produced upon oxygen gas by the process of respiration. The water gasometer was filled with oxygen gas made from the hyperoxygenised muriate of potash by heat, care having been taken to clear all the tubes, &c. as much as possible of common air, by forcing a quantity of oxygen gas through them.

One hundred parts from the water gasometer being treated with the usual tests in the Eudiometer, a residuum of only 2.5 was left; so that 97.5 per cent. were pure oxygen, and the rest azote.

The register of the water apparatus being noticed, and the operator having prepared himself as usual by a forced expiration, began to respire; his pulse was 72; and at the end of 9 minutes and twenty seconds, the experiment was concluded by a forced expiration, when the pulse was raised to 88.

Barom.	Therm. Faht.	Time.	Cubic Inches of oxygen gas inspired.	Cub. Inches expired.	Deficiency.
29.5	53°	9′.20″	3260	3193	67

The operator felt a general glow over the body to the very extremities, with a gentle perspiration; this however went off in a few minutes, and no remarkable deviation from the ordinary state was experienced.

A portion having been saved, as usual, from each of the mercurial gasometers, for an average,

100 parts contained

11 carbonic acid,
83 oxygen,
6 azote.

100

The examination repeated, gave the same results.

Calculation for Carbonic Acid.

100 : 11 :: 3193 : 351.23,

consequently, 351.23 cubic inches of carbonic acid gas were formed in 9′.20″, or 37.64 cubic inches in a minute.

Here it is plain that a greater quantity of carbonic acid was formed from oxygen than from common air, in the same time, and hence we infer, that one use of azote is to regulate the quantity of oxygen, which shall be taken up in the act of respiration.

The gas inspired was 3260 cubic inches, and of this 2.5 per cent. was azote.

100 : 2.5 :: 3260 : 81.50.

The total quantity of azote in the gas inspired, was therefore 81.50 cubic inches.

The quantity of gas expired was 3193 cubic inches, and of this every 100 parts contained six of azote.

100 : 6 :: 3193 : 191.58.

The total quantity of azote in the gas expired, was therefore 191.58 cubic inches; but the total quantity of azote before respiration was only 81.50.

191.58 — 81. 50 = 110.08;

therefore 110.08 cubic inches were added by the process of respiration, beside what little remained in the lungs after the experiment.

Calculation for Oxygen.

The 3260 cubic inches of gas inspired contained 81.50 azote.

3260 — 81.50 = 3178.50,

and consequently the pure oxygen was 3178,50 cubic inches. The 3193 cubic inches of gas expired, contained 83 per cent. of free oxygen, and 11 per cent. in carbonic acid gas, making together 94.

100 : 94 :: 3193 : 3001.42.

The oxygen gas, found after the experiment, was therefore 3001.42 cubic inches, and deducting this from the oxygen before the experiment,

3178.50 — 3001.42 = 177,08.

It appears, at first sight, that 177.08 cubic inches of oxygen were missing, but great part of this may be accounted for, by adverting to the state of the lungs after the experiment.

The addition of 110.08 cubic inches of azote, we consider as arising from that portion still retained in the lungs, notwithstanding the forced expiration at the beginning of the experiment, and considering that in the 14th and 15th experiment, where the same air was repeatedly breathed, the proportion of azote was in the one case 85, and in the other 86 per cent. It seems fair to presume, that the residual air contained in the lungs after a forced expiration may amount in 100 parts, to not more than 16 oxygen and 84 azote: any one who reflects upon the structure of the lungs, and the minute ramifications of the extremities of the bronchial vessels; and when he also considers that those parts of the lungs with which the air comes in contact, if spread out, would present a surface equal to that of the superficies of the whole body; and lastly, that this viscus is so exceedingly spongy and porous, that when once inflated, it is ever after impossible by ordinary mechanical means to expel the air completely, he will easily perceive, not only that a large portion of air must remain for a considerable time in contact with the internal surface of the lungs, where it is liable to lose a portion of its oxygen, but also that the residual quantity of air in the lungs, after the most violent attempts at expiration, may be very considerable. It is to this circumstance that we attribute the excess of azote in the experiments upon oxygen, and pretty deep inspirations of this gas having been made during 9′.20″, the azote must have been in great measure

displaced. Admitting then that the air contained in the lungs, before the experiment, consisted of 16 oxygen, 84 azote, and at the conclusion of the experiment of 94 oxygen, 6 azote, then we have

$\frac{84.x}{100}$ azote at the begining,

$\frac{6.x}{100}$ azote at the end.

$\frac{6x}{100} + 110 = \frac{84.x}{100}$,

$110 = \frac{84x}{100} - \frac{6x}{100}$ or, $84x - .06x = .78x$.

$x = \frac{110}{.78}$ or 141 cubic inches;

Therefore upon this calulation it appears that 141 cubic inches of gas remained in the lungs after a forcible attempt at expiration; then the state of the lungs before the experiment must have been

118.44 azote,
22.56 oxygen.

141

And after the experiment,

132.54 oxygen,
8.46 azote.

141

Calculation on total Quantities.

Azote before the experiment 81.50 cubic inches,
—— contained in the lungs 118,44

199.94

Azote after the experiment,	
—— found by the tests	191.58
—— contained in the lungs,	8.46
	200.04
Oxygen before the experiment,	3178.50
—— contained in the lungs,	22.56
	3201.06
Oxygen after the experiment,	
Found by the tests,	3001.42
Contained in the lungs,	132.54
	3133.96
Total of oxygen before the experiment,	3201.06
Total of oxygen after the experiment,	3133.96
Difference	. . 67.10

The deficiency noticed in the experiment was 67, supposing that the lungs were brought to the same state after as before the experiment; but granting that this was not the case, and that at the close of the experiment the state of the lungs was $141 + 67 = 208$, still our approximation will come within four or five cubic inches, for the azote contained in the sixty-seven missing would be only about four cubic inches. We are aware that the temperature of the lungs being 97, while that of the gas was 53°, the 141 cubic inches would occupy a space equal to 154 cubic inches; but this residual quantity must be greater or less according to the exertion made, and also probably according to the state of the muscular fibre at the time.

Seventeenth Experiment.

The water gasometer was filled to the usual mark upon the scale, with oxygen gas, prepared from about 9 oz. troy, of hyperoxygenised muriate of potash, as in the former experiment; the gas being examined was found to contain as before, 2.5 azote, and 97.5 oxygen, in 100 parts.

The apparatus being found air tight, and all the tubes, &c. cleared of atmospheric air by passing oxygen through them, the operator prepared himself for the experiment; but it must be noticed that he had been rather fatigued during five hours previous to respiring, and had not taken any refreshment; the weather was very warm; his pulse 86; heat under the tongue $98\frac{3}{4}$; he felt no uncomfortable sensation during the process, but experienced a gentle glow and universal perspiration, breathing all the time with great ease, his pulse after the experiment was 102, and the heat under the tongue 99°.

Barom.	Therm. Faht.	Time.	Cub inches. of oxygen gas inspired.	Cub. inches expired.	Deficiency.
30.3	70°	7′.25″	3420	3362	58.

The quantities of expired gas taken off in each of the mercurial gasometers were as under, in the order in which they were filled.

No.	1.	- -	250 cubic inches.
	2.	- -	290
	3.	- -	272
	4.	- -	238
	5.	- -	252
	6.	- -	300

7.	-	-	241
8.	-	-	296
9.	-	-	256
10.	-	-	256
11.	-	-	286
12.	-	-	257
13.	-	-	168
			3362

The 13th gasometer was the whole of the last single and forcible expiration, portions were saved from each of the gasometers, and we first examined the state of No. 1.

100 parts contained 9 carbonic acid,
25 azote,
66 oxygen,
100

The large quantity of azote in this case, was a clear proof that our conjecture upon the residual gas in the lungs was well founded.

We then examined a mixture of No. 2 and 3.

100 parts contained 10.5 carbonic acid,
10 azote,
79.5 oxygen,
100

here the quantity of azote was diminishing, and the ratio of carbonic acid increasing, so that it appears necessary for the lungs to be cleared of azote, before the increased proportion of carbonic acid can take place.

The 13th or last gasometer was now examined by itself; 100 parts contained 12.5 carbonic acid,

5.5 azote,

82. oxygen.

100

Here the proportion of azote was only 3 per cent. more than what existed previously in the gas, and hence we may conclude, that even seven minutes and a half was not a sufficient time to remove the azote from the extremities of the bronchia.

We lastly made a mixture of all the gasometers, from 2 to 12 inclusive, and found that 100 parts contained

12 carbonic acid,

6.5 azote,

81.5 oxygen,

100

Calculation for Carbonic Acid.

100 : 9 :: 250 : 22.50 Carbonic acid gas in No. 1. 22.50

100 : 12.5 :: 186 : 21 ditto No. 13. 21

From 3362 total expired

250 No. 1.

168 No. 13

Deduct 418

Leaves the mixture 2944 of No 2. to No. 12.

100 : 12 :: 2944 : 353.28 Carb. acid gas in mixture 2. to 12. 353.28

396.78

The total quantity of carbonic acid gas emitted, was therefore 396.78 cubic inches.

Calculation for Azote.

100 : 25 :: 250 : 62.50	Azote in No. 1.		62.50
100 : 5.5 :: 168 : 9.24	—— in No. 13.		9.24
100 : 6.5 :: 2944 : 191,36	—— in mixt. 2. to 12.		191.36
			263.10

The azote expired, beside what might be contained in the lungs, at the close of the experiment, was therefore 263.10 cubic inches. Here it is plain, that the operator, at the beginning of this experiment, had not brought his lungs to the same state as in the preceding; or that in consequence of fatigue, and want of refreshment for several hours, the proportion of azote in the lungs might be greater.

Every 100 parts of oxygen, before it was inspired, contained 2.5 azote.

100 : 2.5 :: 3420 : 85.50;

Consequently it contained 85.50 cubic inches of azote.

From 263.10
Deduct 85.50 the original azote,

177.60 will be left for the increase of azote.

Then supposing as before, that the quality of the air in the lungs, before the experiment was 84 per cent. azote, 16 oxygen, and after the experiment 5.5 per cent. azote, 94.5 oxygen, as found in the last gasometer, we take

$\frac{84.x}{100}$ azote at the beginning,

$\frac{5.5x}{100}$ azote at the end;

$\frac{5.5x}{100} + 177.60 = \frac{84x}{100}$

$177.60 = \frac{84x}{100} - \frac{5.5x}{100}$ or $.84\ x - .055\ x = .785x$,

$x = \frac{177.60}{.785}$ or 226 cubic inches.

Hence it appears, that previous to the experiment, the lungs contained in this instance 226 cubic inches, and if we suppose them to be in the same state after, as before the experiment, the quality of the gas in each case will be as follows:

Contents of the Lungs before the Experiment.

189.84 cubic inches of azote,
36.16 oxygen,

226

Contents of the Lungs after the Experiment.

12.43 cubic inches of azote,
213.57 oxygen

226

Calculation for Oxygen.

3420 — 85.50 = 3334.50 original oxygen,
Add 36.16 in the lungs before the experiment,

3370.66 { total quantity of oxygen before the experiment.

After the Experiment.

100 : 66	:: 250	: 165	oxygen in No. 1.	165
100 : 82	:: 168	: 137.76	—— in No. 13	137.76
100 : 81.5	:: 2944	: 2399.36	—— in mixt. 2. to 12.	2399.36
			—— in carbonic acid	396.78
			—— in lungs after expt.	213.57
				3312.47

3370.66 original oxygen,
3312.47 after experiment,

58.19 deficiency.

The observed deficiency in this experiment was 58.

The deficiency in this case, and in the former experiment with oxygen, though comparatively small, when contrasted with the quantity of gas respired, is larger than the average with atmospheric air ; it seems probable, therefore, that a portion may be detained in the system. It must be remembered that what we call residual gas, is not only that contained in the substance of the lungs, and in its appendages, but also that contained in the fauces and mouth.

Eighteenth Experiment.

Barom.	Therm.	Time.	Cub. inches of oxygen gas inspired.	Cubic inches expired.	Deficiency.
30.15	70°	8′.45″	3130	3060	70.

The operator breathed as usual, after having made a strong effort to exhaust his lungs ; his pulse before the experiment was 84, the thermometer under his tongue 98° : after the experiment his pulse was 96, and the thermometer under his

tongue still 98°.; the same gentle glow and perspiration was felt as in the other experiments on oxygen; a portion of the gas was saved from each of the mercurial gasometers, and their amounts were as under:

No.			
1.	-	-	196
2.	-	-	228
3	-	-	284
4.	-	-	294
5.	-	-	248
6.		-	280
7.	-	-	258
8.	-	-	272
9.	-	-	250
10.	-	-	304
11.		-	223
12.			223
			3060

No. 1. tried by itself, contained in 100 parts,

9 carbonic acid,
22 azote,
69 oxygen,

100

No. 12, the last, contained in 100 parts,

12 carbonic acid,
5 azote,
83 oxygen,

100

On account of an accident we cannot give the proportions contained in 2 to 10; but the contents of the first and last gasometers confirm the former experiment, and shews that the proportion of azote continues to diminish, as the experiment proceeds, and also that there is a larger proportion of carbonic acid given off when oxygen is employed, instead of atmospheric air.

In this recital of experiments, which have occupied a considerable portion of time, and attention, we have endeavoured to give a plain statement of facts, from which every one may draw conclusions for himself; we shall here, however, take the liberty of briefly recapitulating the principal of those facts, and submitting what seems to us the most obvious inferences.

1. It appears that the quantity of carbonic acid gas emitted is exactly equal, bulk for bulk, to the oxygen consumed, and therefore there is no reason to conjecture that any water is formed by a union of oxygen and hydrogen in the lungs.

2. Atmospheric air once entering the lungs, returns charged with from 8 to 8.5 per cent. carbonic acid gas, and when the contacts are repeated almost as frequently as possible, only 10 per cent. is emitted.

The 12th and 13th experiments prove, that when the inspirations and expirations are more rapid than usual, a larger quantity of carbonic acid is emitted in a given time, but the proportion is nearly the same, or about 8 per cent. The proportions of carbonic acid gas, in the first and last portions of a deep inspiration, differ as widely as from 3.5 to 9.5 per cent.

3. Considering the 11th as a standard experiment, it appears that a middle sized man, aged about thirty-eight years, and whose pulse is seventy on an average, gives off 302 cubic

inches of carbonic acid gas from his lungs in eleven minutes, and supposing the production uniform for twenty-four hours, the total quantity in that period would be 39534 cubic inches, weighing 18683 grains; the carbon, in which is 5363 grains, or rather more than 11 oz. troy, the oxygen consumed in the same time will be equal in volume to the carbonic acid gas, but it is evident, that the quantity of carbonic acid gas, emitted in a given time, must depend very much upon the circumstances under which respiration is performed; and here it may be proper to notice that all the experiments were made between breakfast and dinner.

4. When respiration is attended with distressing circumstances, as in the 14th and 15th experiments, there is reason to conclude that a portion of oxygen is absorbed; and in the last of these experiments, we may remark, that as the oxygen decreases in quantity, perception gradually ceases, and we may suppose that life would be completely extinguished on the total abstraction of oxygen.

5. A larger proportion of carbonic acid gas is formed by the human subject from oxygen, than from atmospheric air.

6. An easy, natural inspiration, is from 16 to 17 cubic inches in the subject of these experiments, who makes about 19 in a minute; this, however, will vary in different individuals, and perhaps we ought to estimate the quantity of carbonic acid gas, given off in perfectly natural respiration, at somewhat less, and most likely at considerably less, than in the statement above, when we consider that in short inspirations the quantity of air which has reached no farther than the fauces, trachea, &c. bears a much larger proportion to the whole mass respired, than when the inspirations are deep.

7. No hydrogen, nor any other gas, appears to be evolved during the process of respiration.

8. The general average of the deficiency in the total amount of common air inspired, appears to be very small, amounting only to about 6 parts in 1000, and we are inclined to attribute it in great measure to the difficulty in exhausting the lungs as completely after an experiment as before it; the first expiration being made into the open air, the last into the apparatus.

9. The experiments upon oxygen gas prove that the quantity of air remaining in the lungs and its appendages is very considerable, and that, without a reference to this circumstance, all experiments upon small quantities of gas are liable to inaccuracy.

Other important conclusions might perhaps be drawn from the facts related in this paper, but having already trespassed largely upon the time of the Society, we shall abstain from any farther remarks, until we bring forward a new series of experiments.