THE PERCENTAGE OF CARBON DIOXIDE IN EXPIRED ALVEOLAR AIR.

By Ethel C. Pinkerton, B.Sc. (Syd.), Government Research Scholar in the University of Sydney.

(From the Physiological Laboratory of the University of Sydney.)

Introduction.—Since it first appeared probable to physiologists that the exchange in the lungs between the gases of the air and of the blood were governed by the laws of diffusion, attempts have been made to ascertain the composition of the air in contact with the respiratory epithelium of the pulmonary alveoli. The early attempts made by Pflüger (1), Wolffberg (2), and Nussbaum (3) with an inflated balloon surrounding a catheter, by means of which a bronchus could be blocked, and samples taken from the enclosed area, yielded uncertain results under the same conditions. The figures for carbon dioxide were also lower than those obtained by determinations of the tensions of carbonic acid gas in blood and serum. In 1890, Ch. Bohr (4) showed that the tensions of gases in the alveoli could be ascertained from a knowledge of the volume of the expired air, A, and of the volume of the "dead space", a. If the percentage of carbon dioxide in the inspired air be designated by J, the percentage of the same gas in the expired air as E, and in the alveolar air as X,

$$AE = (A - a)X + aJ$$

$$\text{whence } X = \frac{AE - aJ}{A - a}$$

As the figure for the percentage of carbon dioxide in inspired air is negligible, the equation may be simplified to

$$X = \frac{AE}{A - a}$$

Zuntz, his co-workers and pupils, have made use of this method. Owing to the difficulty in measuring the volume of the "dead space", this method is of limited application. It was not until the publication of a method by Haldane and Priestley in 1905 (5), that physiologists accepted the possibility of ascertaining, with some approach to accuracy, the composition of alveolar air. This method was of great simplicity. The breath was forcibly expelled through a long rubber tube connected with the mouth, and the end of the tube at the mouth was closed with the tongue at the termination of the act of expiration. By means of an inlet in the side of the tube close to the mouth, a sample of the last portion of the expired air could be withdrawn from the tube for analysis. This sample was held to be of the same composition as the alveolar air. In order to obtain the mean composition of the alveolar air, the breath was expelled at the close of a normal inspiration, and later at the end of a normal expiration. The mean of the analyses of the last part of these two samples was considered to represent the average composition of the gases of the alveoli. The proof of the nature of the last portion of the air driven out of the lungs in a forced expiration, consisted of analyses of the samples collected after the expulsion of different quantities of expired air. Haldane considered that, if any of the relatively pure air filling the bronchial tubes of the lungs, was mixed with the last part of the air of the sample, there would be a higher concentration of carbon dioxide in the sample collected from a deep expiration than would be present in the sample taken after an ordinary expiration. He gave the results obtained from an experiment in which four samples were collected after sharp expirations of varying depths immediately following the completion of inspiration. The amount of expired air breathed out, by the subject of this experiment, as tidal air, had been found previously to measure 600 c.c. The figures of the analyses of the samples taken under these conditions are given in Table i.

TABLE i.

No. of experiment.	Volume of expired air.	Percentage of carbon dioxide in sample.
1	262	4·42
2	377	5·17
3	492	5·71
4	1050	5·72

The uniformity in the figures yielded in the last two analyses was considered as a proof that the air was derived from the alveoli unmixed with that of the "dead space" of the trachea and respiratory passages lying between the atmosphere around the body, and the alveoli of the lungs.

Haldane further presented a number of analyses (about 54 in all) made on two subjects with the object of measuring the mean composition of the alveolar air. The figures were obtained with the subject at rest in a sitting position, while breathing fresh air at normal atmospheric pressure. The mean concentrations of carbon dioxide were 5·62%, and 6·28% for the two persons, the maximal and mimimal variations being 5·40% and 5·87%, and 5·985% and 6·845% respectively. Haldane commented on the constancy of these figures, which he considered clearly suggested that the ventilation of the lungs during rest was regulated so as to maintain the percentage of carbon dioxide in the alveolar air at an almost fixed level.

In 1893, W. S. Miller(6) made a study of the structure of the human lung, after he had studied the morphology in Necturus, the frog, the snake, the crocodile, the turtle, Heloderma (lizard), the fowl, cat, dog, rabbit and sheep. He employed dried specimens of the lungs, corrosion-preparations in wax or Wood's metal, and reconstructions from sections. The paper, which remained little recognised for many years, now forms the basis of our conception of pulmonary structure. The terminal bronchiole opens out into a club-shaped expansion, from which five or six openings, or "vestibula", lead to secondary expansions known as "atria", which communicate with central cavities or "air-sacs" set about with the small, irregular cubicles or "air-cells". The "air-cells" correspond to the alveoli of physiological writers. These structures are found not only in the walls of the air-sacs, but also in those of the atria. Alveolar air, as understood by physiologists, represents that part of the gaseous contents of the lungs filling the "air-cells" belonging to the "air-sacs".

The composition of the alveolar air has been made the subject of repeated investigations by Krogh and Lindhard. Lindhard(7) measured the percentage of carbon dioxide in the alveolar air by a method worked out in the laboratory of the Finsen Institute at Copenhagen. He took a series of samples at the end of a number of respirations, and analysed the mixed sample. Lindhard pointed out that Haldane's method presupposed that the last air expired, had the same content in carbon dioxide as the alveolar air at the end of an expiration. This, he considered, was not the case, as the last air to leave the alveoli remained in the upper air-passages in what is known as the "dead space". The error produced in this way always tended in one direction. The percentage of carbon dioxide in the expired portion would be smaller than that in the alveoli. The value of the error would vary with the length of the expiration. Not only so, but the "form" of a respiration varied with its depth.

Krogh (8) pointed out that the term "average alveolar air", or simply "alveolar air", had two distinct meanings. It might refer to the air in the pulmonary air-cells, or it might refer to the last air expired during expiration. He proposed, therefore, to designate the latter air as "the alveolar expired air". He concluded that the average alveolar tension of carbon dioxide could not be determined with certainty by any method hitherto employed. During rest, Haldane and Priestley's method yielded the nearest approximation, but, during work, the results obtained by this method were much too high. The percentage of carbon dioxide in the "alveolar expired air" was not identical with the average tension of carbon dioxide in the alveoli, but generally lower. Krogh and Lindhard (9), using mechanical methods of sampling the expired air, made a careful study of the distribution of carbon dioxide in expired air under conditions of work and rest. They showed that, during work, the carbon dioxide increases directly with the time at which the sample of expired air is taken for analysis. Each successive portion of expired air contained more carbon dioxide than the portion which preceded it, and less than the portion which followed it. With the body at rest, they found that the percentage of carbon dioxide in the expired air increased rapidly at first, and later more slowly, the curve showing a marked tendency to become asymptotic.

In a critical examination of the methods for measuring the volume of the "dead space", Henderson, Chillingworth and Whitney (**10**) determined the composition of successive portions of the expired air. They found that the concentration of carbon dioxide in the expired air increased in each successive portion expelled from the air-passages. Their experiments ceased when the volume of expired air amounted to 400 c.c., possibly because they were concerned with tidal respiration, and did not wish to produce dilatation of the small bronchioles by forcible expiration. They state that 400 c.c. are sufficient to remove the whole of the air from the "dead space", and that the final samples of expired air consisted of undiluted alveolar air. Their published curve shows, however, that the concentration of carbon dioxide was still rising when their experiments ceased. To this publication, Haldane (**11**) appended a paper, in which he discussed again the evidence in support of the determination of the composition of alveolar air by the method of 1905. He stated that "it now appears that the air of constant carbon dioxide pressure is alveolar air from the 'air-sacs' of Miller's nomenclature, and that the air from the alveoli of the 'atria' is of a different and more variable composition." A series of 17 analyses was given to extend the observations on the concentration of carbon dioxide after the expiration of different amounts of air. The average figures are published in a table, reproduced as Table ii.

TABLE ii.

Depth of respiration.	Percentage of CO_2 in air issuing from the mouth.
190	3·03
335	4·37
510	5·04
650	5·19
950	5·51
1350	5·48

In a further series on a different day, the results of six successive determinations gave the mean percentage of carbon dioxide as 5·39 with an expiration of 900 c.c., and 5·36 with an expiration of 1750 c.c. Haldane concluded that the deeper part of the expiration contained no more carbon dioxide than the middle part.

Scope of Research.—The experiments to be described in the present paper are designed to estimate the percentage of carbon dioxide in successive portions of expired air. They were undertaken in consequence of repeated failures in the Physiological Laboratory to obtain any close agreement in the concentration of carbon dioxide in different samples of alveolar air, collected after the method of Haldane and Priestley. Instead of observing any constancy in these values, even when averaged results were obtained of five samples taken at the close of inspiration, and of five taken at the close of expiration, as described by H. G. Chapman (**12**), the values obtained showed variations of 5% or even more. It became necessary to ascertain whether the percentage of carbon dioxide increased in the last 600 c.c. of air expressed from the air-passages in a forcible expiration.

The air issuing from the mouth was passed along a brass tube of sufficient length to accommodate the greater part of the expired air. The mouthpiece was of such a size and shape as to be closed readily by the lips, so that the whole of the air discharged from the air-passages entered the tube without admixture with the atmosphere. At the conclusion of the expiration, the mouthpiece could be securely shut by the tongue. The expired air was collected from different subjects and under varying conditions. As a rule, no attempt was made to get uniform results by resting in a chair for some minutes with regular breathing. The air was expelled forcibly, sometimes at the end of inspiration, and sometimes at the end of expiration, sometimes after shallow breathing, and sometimes after several deep breaths. As it was only desired to know how the percentage varied in the successive parts of the later portions of the expired air, it became unnecessary to pay attention to these factors, when it was found that none of them caused any variation in the character of the results. Small, metal, capillary tubes inserted into the sides of the brass tube served for withdrawing samples for analysis. These capillary tubes were placed at intervals of 25 cm. along the first two metres of the tube. Sampling was performed by attaching burettes in which a vacuum of 50 to 100 c.c. was produced by lowering the mercury reservoir, and clamping the tube connecting the reservoir to the burette. The upper nozzles of the burettes were connected by short pieces of pressure india-rubber-tubing controlled with strong spring clamps. The analyses were made in a Hempel's pipette with a sample of 50 c.c. contained in a gas burette graduated in fifths of 1 c.c. The readings were made to the nearest tenth. These readings were easily possible as the divisions on the scale were 1 mm. apart. As the change in volume during absorption varied from 1·5 c.c. to 4 c.c., the analytical error might amount to 0·2 on the calculated percentage of carbon dioxide. A number of analyses were done in duplicate, and the figures show the agreement between the duplicates to be good. In no case did the difference in the calculated percentage amount to more than 0·1. In the opinion of Krogh(**13**), it is misleading to give the average alveolar tension of carbon dioxide with an accuracy of more than 0·5 mm. Hg., as the analytical figures should not be strained too far.

Control of Experimental Method.—The air leaving the alveoli of the lung traverses the tubular air-passages before reaching the mouth. It is recognised that a certain amount of alveolar air must be passed through these tubes before the air present in them is dislodged. When the air issuing from the mouth travels through a long tube, the same general conditions will prevail. A considerable amount of expired air will be diluted with the air in the tube before the whole of this is removed. It is now known that, when a stream of gas is passed along a tube, an axial stream traverses the centre of the tube, and that a "spike" of the entering gas is thrust into the air that is present. The "spike" is more slender and elongated the more rapid the speed of the entering gas.

A series of experiments has been carried out to ascertain what amount of gas was needed to wash out the tube, when passed into the brass tube, in a small fraction of a second. Since a column of gas passes through a straight tube for a long distance in the form of a spike when there is no resistance in the tube, the tube employed was lightly packed with glass wool for three inches. The brass tube used in the experiment had a bore of 20 mm., and was 5 metres long. It was perfectly straight. A brass mouthpiece, 5 cm. long and of 15 mm. bore, was soldered at one end of it, and a coiled rubber-tube, 2 metres long, was attached to the opposite end, the end of the rubber-tubing dipping into a vessel of water. The total volume of the brass and rubber tubes was approximately 2,200 c.c. Just beyond the mouthpiece and at intervals of 25 cm., capillary brass tubes were securely soldered with silver into the main tube. These served for the withdrawal of samples. The gas to be used in the experiment was placed in a strong air-tight vessel. This vessel was fitted with a cork through which passed two bent glass tubes, by means of which the vessel could be connected to the water-supply, and also to the mouthpiece of the brass tube. The vessel was completely filled with water, which was displaced by a mixture of air and carbon dioxide. The rubber tubing, connecting the vessel to the monthpiece of the brass tube, was tightly clamped with a strong spring clip, and the interior of the vessel was connected with the water-supply so that the gas in the vessel was strongly compressed. When the pressure was sufficient, the connection with the water-supply was clamped off. The clamp connecting the gas with the tube was released for a fraction of a second, and at once retightened. As the far end of the tube was under water, no air could be sucked in as a result of any change in the volume of the air in the tube. The volume of the vessel containing the gaseous mixture in the first set of experiments was three litres, which was compressed to half its volume by the water-pressure. Later, a larger vessel holding 11,750 c.c. was employed. In this, the amount of compression of the gaseous mixture was varied. In the later series, the end of the hose was so placed that the volume of gas passed through the tube, could be measured. The results of the first sets of experiments are recorded in Table iii.

Table iii.

No. of experiment.	Volume to which the gas was compressed in cubic centimetres.	Percentage of CO_2 in samples of the gas collected at distances from the mouthpiece of			
		25 cm.	50 cm.	175 cm.	200 cm.
1	2500-1500	4·1	4·0	4·1	4·2
2	3000-1500	3·2	3·3	3·3	3·3
3	3000-1500	3·7	3·7	3·8	3·7
4	3000-1500	3·7	3·7	3·7	3·7
5	3000-1500	2·7	2·7	2·8	2·8
6	3000-1500	32·0	32·1	32·0	32·1

The analyses show the percentage of carbon dioxide in the two successive samples taken near the mouthpiece, and the two samples withdrawn at 175 cm. and 200 cm. from the mouthpiece. The samples farthest from the mouthpiece were taken first. The volume of the tube, to the outlet at 200 cm., was 625 c.c. approximately. These analyses show that the percentage of carbon dioxide in the air along the tube was constant for the distance tested. Such differences as do appear in the figures are within the error of analysis. In the first five experiments, the percentage of carbon dioxide was varied between 2·7 and 4·1. In the sixth experiment, the percentage of carbon dioxide was 32. In the second series of experiments, recorded in Table iv., the volume of the gas driven into the tube was measured. This was found necessary, as the brief release of the spring-clamp did not permit of the whole of the compressed gas passing into the tube.

Table iv.

No. of expt.	Volume of gas passed through tube in c.c.	Volumes to which the gas was compressed in c.c.	Percentage of CO_2 in samples of the gas collected at distances from the mouthpiece of			
			25 cm	50 cm.	175 cm.	200 cm.
1	...	11000-8750	34·4	34·7	34·7	34·6
2	800	11250-8750	23·7	23·6	23·6	23·6
3	700	11000-9750	14·2	14·0	14·1	14·2
4	1150	11250-8750	23·4	23·3	23·4	23·4
5	1150	11250-8750	15·8	15·8	15·8	15·6
6	1000	10750-8750	21·6	21·6	21·7	21·5
7	1200	11250-8750	13·2	13·3	13·2	13·3
8	1300	11500-8750	9·3	9·4	9·3	9·3
9	1200	11500-8750	5·9	6·0	5·9	6·0

The figures show that the percentage of carbon dioxide, in the 600 c.c. passed last into the tube, remained constant within the analytical error of the experiment, even when such small quantities as 700 or 800 c.c. were released into the tube. The percentage of carbon dioxide was varied from 6 to 34·6. These results show that quantities of gas, of similar volume to that expelled from the lungs by a forcible expiration, wash out the air from the last 200 cm. of the brass tube.

Results.—Numerous experiments were carried out after samples of expired air had been passed along the brass tube. As an example, some experiments carried out, with the author as subject, may be described in some detail. The brass tube used was that employed in the control-experiments with the gaseous mixture. The samples withdrawn in the first series were taken at 25 cm. and 200 cm. from the mouthpiece. Each sample measured about 80 c.c., and was analysed in two portions. The samples distant from the mouthpiece were collected before those nearer to it. The volume of the air driven from the tube was measured in a spirometer. A number of breaths were discharged into the tube before the particular breath from which the sample was taken. The results are recorded in Table v.

TABLE V.

No. of expt.	Date.	Time of sample given.	Volume of expired air in c.c.	Percentage of CO_2 in samples of alveolar expired air collected at distances from the mouthpiece of			
				25 cm.		200 cm.	
1	15.v.16	a.m.	2400	4·2	4·3	4·0	4·0
2	16.v.16	a.m.	2400	5·0	4·9	4·4	4·5
3	16.v.16	p.m.	2400	4·3	4·4	4·4	4·5
4	16.v.16	p.m.	2200	4·4	4·5	4·3	4·3
5	16.v.16	p.m.	2200	4·5	4·5	4·2	4·1
6	17.v.16	a.m.	2200	4·5	4·4	4·4	4·5
7	17.v.16	p.m.	2400	4·0	4·1	4·1	4·1

The two metres of the brass tube in connection with the mouthpiece contained the last 625 c.c. expelled from the air passages. One sample represented the last 150 c.c. of expired air to leave the mouth, while the other represented the composition when half a litre less was expelled. The figures show that the composition had not changed on four occasions when an extra half litre had passed along the tube; while, on three occasions, the last part of the expired air contained a greater amount of carbon dioxide. The mode of sampling was then varied slightly, two samples being taken at 25 cm. and 50 cm. from the mouthpiece, and two at 175 cm. and 200 cm. The volume of air expelled was also diminished. The results are recorded in Table vi.

TABLE vi.

No. of expt.	Date.	Time sample given.	Volume of expired air in c.c.	Percentage of CO_2 in samples of alveolar expired air collected at distances from the mouthpiece of			
				25 cm.	50 cm.	175 cm.	200 cm.
1	23.v.16	a.m.	†2500	3·4	3·5	3·5	3·5
2	25.v.16	a.m.	1900	4·5	4·4	4·4	4·4
3	25.v.16	a.m.	1900	4·2	4·2	4·1	4·2
4	25.v.16	p.m.	1750	4·1	4·2	3·7	3·8
5	30.v.16	p.m.	1250	4·5	4·5	4·5	4·5
6	30.v.16	p.m.	1400	4·6	4·6	4·5	4·6
7	30.v.16	p.m.	1500	4·3	4·2	4·1	4·1
8	31.v.16	a.m.	1550	4·4	4·4	4·4	4·3
9	1.vi.16	a.m.	1550	4·5	4·4	4·4	4·3
10	1.vi.16	a.m.	1400	4·6	4·5	4·6	4·5
11	1.vi.16	a.m.	1200	4·9	4·9	4·8	4·8
12	1.vi.16	p.m.	1400	4·4	4·3	4·4	4·3
13	1.vi.16	p.m.	1350	4·7	4·7	4·7	4·7
14	2.vi.16	a.m.	1550	5·3	5·2	5·1	5·1
15	2.vi.16	p.m.	1300	4·4	4·5	4·3	4·4
16	6.vi.16	p.m.	1200	4·6	4·7	4·6	4·6
17	6.vi.16	p.m.	1250	4·7	4·7	4·7	4·7

† After a deep inspiration.

These results show that the gas along the tube did not vary in thirteen out of the seventeen experiments; while, in experiment No. 4, there was distinctly more carbon dioxide in the air near the mouthpiece; and, in experiments Nos. 7, 9, and 14, there seemed to be slightly more carbon dioxide in the air breathed later from the mouth. In these three experiments, the difference in composition is so slight as not to be detectable with certainty by the method of analysis. If Tables v. and vi. be compared, it will be seen that there is a decided change in the results. When the quantity of air expelled from the mouth was over two litres, the amount of carbon dioxide in the tube was more often higher near the mouthpiece than when the quantity of expired air was less. The fact demonstrated in these Tables, that the more air expelled from the lungs, the greater was the tendency for the percentage of carbon dioxide to increase continuously as the air left the mouth, suggested that the time occupied in breathing out the air affected the result. Experiments, therefore, were carried out in which the air was expelled slowly during several seconds, and others during which the air was expelled more rapidly. Two seconds represent the minimal time in which the subject could expel two litres of air. The experiments in which the air was expired less quickly may be recorded first. In these experiments, the conditions were exactly similar to those of the experiments recorded in Table vi. The results appear in Table vii.

Table vii.

No. of expt.	Date.	Volume of expired air in c.c.	Percentage of CO_2 in samples of alveolar expired air collected at distances from the mouthpiece of			
			25 cm.	50 cm.	175 cm.	200 cm.
1	25.x.16	1800	4·7	4·7	4·5	4·4
2	26.x.16	1700	5·3	5·2	5·0	4·9
3	26.x.16	1800	4·9	4·9	4·7	4·7
4	26.x.16	1600	5·4	5·4	5·2	5·0
5	30.x.16	1800	4·9	4·8	4·5	4·3

These results show that, when the air leaves the lungs during several seconds, the alveolar expired air contains more carbon dioxide the longer the expiration continues. The successive portions of the expired air thus show an increased concentration of carbon dioxide, the later they leave the air-passages.

As it was thought that removing the samples from the brass tube might bring about a mixing of the contents, which might obscure any slight difference in the composition of the air in the several portions of the brass tube, the apparatus was varied by making the brass tube in separate portions connected together by rubber-tubing, which could be clamped so that each part of the brass tube could be isolated. Four portions of brass tubing, of 12 mm. bore and 79 cm. length, holding about 100 c.c., were fitted near the centre with capillary tubes for withdrawing samples of the gas. These tubes were placed in series as *a*, *b*, *c*, and *d*, and connected with a mouthpiece 5 cm. long. The last portion (*d*) was connected with a brass tube similar to that used in the earlier experiments. This brass tube was one metre long, and, to its end, two metres of rubber-tubing were attached. These later experiments were performed in the same way as the earlier ones. As soon as the subject had breathed into the tube, the clamps between the successive brass tubes were tightened, and the samples collected. The results of some experiments are recorded in Table viii.

TABLE viii.

No. of expt.	Date.	Time sample given.	Volume of expired air in c.c.	Percentage of CO_2 in samples of alveolar expired air collected from			
				a	b	c	d
1	30.vi.16	...	900	4·6	4·4	4·3	4·3
2	3.vii.16	...	1000	4·2	4·1	4·1	4·2
3	16.x.16	a.m.	1650	4·2	4·3	4·3	4·4
4	16.x.16	a.m.	2000	*5·7	5·7	5·6	5·6
5	16.x.16	a.m.	2000	4·0	3·9	4·0	4·0
6	16.x.16	p.m.	2100	†3·6	3·6	3·5	3·7
7	16.x.16	p.m.	2300	4·1	4·1	4·1	4·1
8	16.x.16	p.m.	2200	4·2	4·2	4·2	4·1
9	17.x.16	a.m.	2000	†3·3	3·4	3·3	3·3
10	17.x.16	p.m.	2100	4·5	4·5	4·6	4·5
11	17.x.16	p.m.	2000	4·5	4·5	4·6	4·5
12	17.x.16	p.m.	1800	4·4	4·3	4·4	4·3

* After exercise. † After a deep inspiration.

In most experiments, the expired air was expelled as rapidly as possible by the subject (time of expiration ascertained to be two seconds for the deep expiration, and one second for the shallow expiration), but in one experiment (1), the expulsion occupied two seconds.

The results show that, when the expulsion was made rapidly in the times mentioned above, the last portions of the expired air contained a similar percentage of carbon dioxide. When, however, the expiration was less rapid, the successive samples showed an increase in concentrations of carbon dioxide.

The time occupied in breathing out various amounts of air as quickly as possible from the lungs was found approximately with the aid of a stop-watch. The figures obtained from sixty experiments, in which the time was noted, are:—

For 1000c.c. expired, the average 0·5 sec., max. 0·6 sec., min. 0·4 sec.
For 1200c.c. expired, the average 0·65 sec., max. 0.8 sec., min. 0·5 sec.
For 1500c.c. expired, the average 1·1 secs., max. 1·5 secs., min. 0·9 sec.
For 1800c.c. expired, the average 1·9 secs., max. 2·2 secs., min. 1·8 secs.
For 2000c.c. expired, the average 2·0 secs., max. 2·5 secs., min. 1·4 secs.
For 2200c.c. expired, the average 2·5 secs.

A study of a graph constructed from these figures shows that, after 1300 c.c. had been expelled from the lungs, the rate of expulsion became distinctly slower; and that the speed of expulsion was approximately diminished to one-half its former value.

Discussion.—These results, which are confirmed by those with two other subjects, show that the last air expired is of uniform composition within the error of analysis, provided that the expiration was made quickly. When the total expired air amounted to one litre, the last 625 c.c. contained a uniform percentage of carbon dioxide after the air had been expelled from the mouth in less than one second. It would thus appear that this last 625 c.c. was not mixed with any part of the air of the "dead space." While it is no doubt true that the percentage of carbon dioxide in the pulmonary air-cells is continuously increasing during the expiratory phase, it is not possible, when the subject is not doing heavy work, to obtain any evidence of an increase in the percentage of carbon dioxide during a deep, forcible expiration unless this is unduly prolonged. Even when much deeper expirations were made, which occupied two seconds, it still remained impossible to detect any increased tension of carbon dioxide in the air last expired. In the light of these results, it seems unlikely that the expired air remaining in the "dead space" differs in composition from that last expelled from the mouth or nose during a quick, forcible expiration. Whether the air was forcibly expelled at the end of an inspiration, after deep breathing or after shallow respiration, the same results were obtained. The last 625 c.c. expired appeared to be of uniform composition. The bearing of these results on the conclusion of Krogh and Lindhard, that the percentage of carbon dioxide in the alveolar expired air is not identical with that in the pulmonary alveoli, will be discussed in a later paper dealing with alveolar expired air.

Conclusions.

(1.) The forcible expulsion of the breath into a straight brass tube of 20 mm. bore serves to wash out the whole of the air from two metres of the tube.

(2.) Analysis of the last 625 c.c. of expired air shows that the difference in percentage of carbon dioxide, in any portion of it, does not exceed the error in the analytical method, when the expulsion is performed within two seconds for amounts of two litres and over, and within one second for quantities of one to two litres of expired air.

(3.) When the air is expelled more slowly, the successive portions of expired air continue to show higher percentages of carbon dioxide.

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