THE COMPOSITION OF EXPIRED ALVEOLAR AIR.

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

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

In a previous communication(1) dealing with the percentage of carbon dioxide in expired alveolar air, it has been shown that the amount of carbon dioxide in the last 625 c.c. of expired air does not vary beyond the error of the analytical method, when the expulsion has been performed within two seconds, for quantities of air of two litres or over, and within one second for quantities of one to two litres of expired air. The investigation of the composition of expired alveolar air has now been extended to the estimation of oxygen as well as carbon dioxide, and more accurate analytical methods have been employed for the determinations of the amounts of the gases.

Methods.—The samples of air have been obtained in the same way as in the previous research(1) by collecting them through small capillary pipes set in a long brass tube, into which the subject of the experiment breathed. The tube is the same as used previously, and the capillary tubes have been fixed 250, 500, 1750 and 2000 mm. from the mouthpiece. The analyses of the gases of the samples have been performed in a large Haldane apparatus, the carbon dioxide being absorbed by potash, and the oxygen by alkaline pyrogallic acid. The carbon dioxide can be estimated to 0·01 c.c. in a measurement of 1 c.c., giving an analytical error of 1 in 100. The percentages of carbon dioxide in the samples are calculated, therefore, to the second decimal place. The error in the determinations of oxygen has been ascertained in a series of

estimations of the amount of oxygen in the air of the room. The results of these analyses are given in Table i.

Table i.

Date.	Bar. Press. mm. Hg.	Temp. °C.	Percentage of oxygen obtained.	Average per-centage.	Range.
11.vii.17	764·8	16·1	20·90, 20·87, 20·87, 20·88, 20·84, 20·81	20·86	±0·05
12.vii.17	758·0	14·7	20·93, 20·94, 20·97	20·95	±0·02
16.vii.17	755·6	16·5	20·87, 20·86, 20·89	20·87	±0·02
18.vii.17	747·0	14·3	20·89, 20·87, 20·88, 20 85, 20·90, 20·91	20·88	±0·03

The figures in this Table for the oxygen in the air of the room have varied from 20·81 to 20·97%. These figures are all somewhat lower than 20·96, but the differences between the analyses on different days do not exceed 0·16 parts in 20·89 parts of air, and the duplicates do not vary by more than 0·09 parts in the same quantity. In the first series of experiments, a plug of glass-wool was placed in the brass tube, as proposed by Henderson, Chillingworth and Whitney(2), but this was omitted in a second series. The omission of the plug of cotton-wool has made no difference to the ease with which the breath displaced the air in the brass tube. It would appear that the expired air is driven into the tube at such a rate, that the air already in the tube is displaced by the advancing wave of the entering air. I am indebted to Mr. F. W. Carpenter for the suggestion, that the air respired into the brass tube behaves like an "explosive wave," driving the contents of the tube before it.

Results.—As it felt easier to breathe quickly into the empty brass tube, and as the results of the analyses show the least change along the tube, the results of the second series of experiments, in which no glass-wool was placed in the brass tube, will be described first. The figures are given in Table ii.

TABLE ii.

No. of expt.	Volume of expired air in c.c.	Percentage of O_2 in samples of expired alveolar air, collected at distances from the mouthpiece of				Percentage of CO_2 in samples of expired alveolar air, collected at distances from the mouthpiece of			
		25 cm.	50 cm.	175 cm.	200 cm.	25 cm.	50 cm.	175 cm.	200 cm.
1	1150	15·73	15·58	15·77	15·77	4·80	4·83	4·72	4·72
2	1250	16·40	16·42	16·47	16·46	4·52	4·54	4·45	4·41
3	1250	16·35	16·41	16·44	16·45	4·44	4·47	4·41	4·37
4	1275	15·94	16·02	16·04	16·01	4·71	4·71	4·68	4·64
5	1300	16·17	16·22	16·19	16·21	4·65	4·66	4·59	4·57
6	1300	16·32	16·40	16·58	16·61	4·42	4·43	4·32	4·32
7	1450	16·44	16·39	16·69	16·54	4·41	4·44	4·29	4·26
8	1475	15·74	15·71	15·89	15·91	5·02	5·00	4·87	4·89
9	1550	16·92	16·93	16·97	17·03	4·34	4·26	4·27	4·26

The results are arranged in the order of the volume of the expired air. The expired air has been expelled as quickly as possible from the lungs. The brass tube contains 625 c.c. between the mouthpiece and the outlet, 200 cm. from the mouthpiece. The results show that the air, filling the brass tube, in the neighbourhood of the outlets at 25 cm., and 50 cm., invariably contains slightly less oxygen, and slightly more carbon dioxide than that in the neighbourhood of the outlets at 175 cm., and 200 cm., from the mouthpiece. The difference in experiment 9 amounts to less than 0·07% oxygen, and to less than 0·04% carbon dioxide; while, in experiment 7, the difference amounts to 0·02% oxygen, and to 0·15% carbon dioxide, the greatest difference observed in this series. It would thus appear that, in a respiration of about 1300 c.c., the last 625 c.c. show a change in composition of not more than 0·15% carbon dioxide, and 0·20% oxygen. The range of variation in the composition of the last 625 c.c. to be expelled from the lungs depends on the speed with which the air is driven into the brass tube. The quicker the air enters, the more uniform is the composition of the last portion. As the period of expiration becomes prolonged, the percentage of carbon dioxide in the last part of the expired alveolar air rises, while the percentage of oxygen falls (*vide* experiment 4 of Table iii.).

A more extensive series of figures has been obtained in the first set of experiments, in which glass-wool was placed in the brass tube. The results, arranged according to the depth of the expiration, which varied from 900 c.c. to 1625 c.c., are recorded in Table iii.

TABLE iii.

No. of expt.	Volume of expired air in c.c.	Percentage of O_2 in samples of expired alveolar air, collected at distances from the mouthpiece of				Percentage of CO_2 in samples of expired alveolar air, collected at distances from the mouthpiece of			
		25 cm.	50 cm.	175cm.	200cm.	25 cm.	50 cm.	175cm.	200cm.
1	900 (	16·62	16·58	16 69	16·68	4·24	4·21	4·11	4·08
	duplicates)	16·54	16·57	16·70	16 70	4·20	4·23	4·12	3·99
2	1000	16·62	16·69	16·98	17·06	3·98	3·97	3·77	3·74
3	1025	17·05	16·99	17·24	17·30	4·02	4·08	3·91	3·84
4	1050	16·68	16·86	16·92	16·95	4·37	4·14	4·24	4·17
5	1100	16·12	16·30	16·36	16·52	4·62	4·51	4·46	4·35
6	1125	15·99	16·05	16·07	16·13	4·48	4·43	4·53	4·37
7	1175	16·77	16·76	16·77	16·71	4·03	4·12	4·09	4·03
8	1175	16·56	16·57	16·75	16·74	4·28	4·27	4·22	4·15
9	1200	15·70	15·76	15·93	15·98	4·70	4·71	4·54	4·54
10	1290	16·81	16·71	16·84	16·87	4·04	4·03	3·94	3·88
11	1200	16·99	16·88	16·98	17·08	4·26	4·28	4·13	4·08
12	1300	16·62	16·70	16·83	16·90	4·17	4·13	4·05	3·99
13	1325	16·82	16·94	17·03	17·08	4·25	4·18	4·12	4·08
14	1325	16·73	16·77	16·97	17·00	4·23	4·22	4·10	4·04
15	1325	16·27	16·28	16·30	16·39	4·39	4·40	4·35	4·30
16	1325	16·61	16·70	16·80	16·81	4·04	4·06	3·88	3·88
17	1350	16·37	16·42	16·39	16·48	4·20	4·17	4·13	4·10
18	1400	15·90	15·96	16·08	16·10	4·76	4·70	4·71	4·63
19	1425	16·26	16·35	16·54	16·60	4·31	4·31	4·19	4·13
20	1425	16·23	16·30	16·47	16·56	4·29	4·30	4·18	4·13
21	1450	16·47	16·54	16·64	16·66	4·57	4·58	4·53	4·51
22	1450	16·64	16·56	16·63	16·66	4·22	4·31	4·27	4·24
23	1625	16·40	16·35	16·51	16·56	4·41	4·32	4·18	4·22

The figures show that the expired air, which is collected at a distance of 200 cm. from the mouthpiece, contains more oxygen and less carbon dioxide than that leaving the lungs at the end of expiration. In two experiments, viz., Nos. 7 and 22, there appears to be no evidence of any change in composition in the portion of expired alveolar air examined. In experiment 2, the difference amounts to 0·36% oxygen, and to 0·22% carbon dioxide, the

greatest difference observed in this investigation. The total volume expired in experiment 2 is 1000 c.c., so that the composition of the last 600 c.c. does not vary by more than 0·36% oxygen, and 0·22% carbon dioxide. In experiment 9, which is typical of many, the oxygen has decreased 0·22%, and the carbon dioxide diminished 0·16%.

From these two series of experiments, it appears that the carbon dioxide increases slowly in the expired air during a rapid expiration. The rate of increase varies, but, in the last 600 c.c. expelled from the lungs, the increase is not more than 0·22% carbon dioxide, while it is not more than half this figure in 17 out of 32 experiments.

Discussion of Results.—Two methods have been used recently to examine the composition of successive portions of the air expired. Haldane(3) has measured the percentage of carbon dioxide in the final portion of the air breathed out during a series of expirations of increasing depth. He has concluded, from his results, that the deeper part of an expiration contains no more carbon dioxide than the middle part. Krogh and Lindhard(4) have examined successive portions of the air breathed out during work, the samples being collected at intervals of some hundredths of a second. They have found that each successive portion of the expired air contains more carbon dioxide than that which precedes it, and less than that which follows it. They have been unable to apply this method to the examination of the breath expired when the body is at rest, but they have employed a modification, whence they conclude that the percentage of carbon dioxide rises slowly at the end of a normal respiration, the curve of the concentration of carbon dioxide in the breath showing a marked tendency to become asymptotic.

The method used in this paper makes it possible to examine the composition of a part of the air of the same breath to a certain degree of accuracy. When the analysis is made sufficiently delicate, it is possible to detect a change in the composition of the final 600 c.c. expelled from the air-passages. The concentration

of carbon dioxide increases by a variable amount in different experiments, but never more than 0·22%, while the increase can hardly be detected in some experiments. The percentage of oxygen diminishes by not more than 0·36%.

In considering which of these methods yields the most correct information as to the composition of the expired air, it may be noted that Haldane's experiments have been made on different respirations. His method of estimating carbon dioxide has been sufficiently accurate to detect the change of composition, but the fact that he obtained his samples at various depths of respiration from different breaths has not permitted him to recognise small differences in concentration. Krogh observed the change of concentration during work by analysis of successive samples collected at consecutive intervals of time, but, for conditions of rest, his curve was mainly the result of interpolation. In the method employed in this investigation, the analyses are made on successive portions of the same respiration. When the gaseous analysis has only been capable of recognising the change of concentration of 0·2% in the amount of carbon dioxide, the composition of the final 600 cc. expired has appeared uniform; but, with greater delicacy, a change in concentration of not more than 0·22% of carbon dioxide, and 0·36% oxygen has been observed.

These results are in accord with the results of Krogh and Lindhard. They support Lindhard's contention(4), that the final portion of the expired air has not the same composition as the air in the alveoli of of the lungs, since the portion of the alveolar air in the trachea and bronchioles will contain more carbon dioxide, than the air expelled from the mouth, as it leaves the alveoli later.

Conclusions.

(1) Estimations of the percentage of oxygen and carbon dioxide in the successive portions of air rapidly expelled from the lungs, show that the concentration of carbon dioxide diminishes by not more than 0·22% in the final 600 c.c., respired, and that the concentration of oxygen augments by not more than 0·36% in the same portion of the breath.

(2) The change in concentration is independent of the depth of respiration, but depends on the speed with which the air is expired. The more slowly the air is breathed out, the greater the change in concentration of the gases of the final portion.

(3) These results lead to the inference, that the alveolar air in the pulmonary atria at the end of an expiration contains a lower concentration of oxygen and a higher concentration of carbon dioxide, than the air last expelled from the mouth in the rapid expiration.

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Addendum.—Seven sets of analyses with Haldane's apparatus were made on the contents of the brass tube after washing it out with gaseous mixtures containing known amounts of carbon dioxide. The results demonstrated the completeness of the replacement.

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