Composition of the Blood Gases during the Respiration of Oxygen.

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The effect of breathing oxygen-rich gas mixtures on men and animals has been frequently investigated. The papers which we have consulted deal exclusively with methods in which the respiratory exchange was studied, and the general results of the more recent experiments confirm the view that there is little or no difference in metabolism, as indicated by the gaseous exchange, whether ordinary air or gas mixtures rich in oxygen are respired.* A contrary opinion has been formed by some observers, such as Rosenthal† and Lukjanow.‡ We have been unable to find any paper later than the work of P. Bert which deals with the composition of the blood gases during oxygen inhalation. While engaged on a study of the nitrogen-content of the blood we accumulated a mass of data on the comparative quantities of carbon dioxide and oxygen in the blood of cats breathing air and high percentages of oxygen. These results we bring forward in this paper.

The cats were anæsthetised with urethane. The process for obtaining the samples of blood, the precautions to be taken in the evacuation of the gases by the tapless form of blood pump, were those described at length in a former paper,§ in which the mode of administration of oxygen has also been fully described. Respiratory tracings were taken in every case, but we do not consider it necessary to reproduce these.

In many of the experiments, but unfortunately not in all, as these were originally made with another object, determinations were made of the hæmoglobin content by the Gowers-Haldane hæmoglobinometer.

It has been stated by August Krogh that "the hæmoglobin of different animals does not necessarily possess the same relative affinity for oxygen and carbonic oxide."|| If this is true, then the hæmoglobin of the blood of

* (1) Speck, 'Archiv f. d. gesammte Physiologie,' 1879, vol. 19, p. 171; (2) Loewy, 'Übersuchungen über die Respiration und Circulation,' Berlin, 1895; (3) Arnold Durig, 'Archiv f. Physiologie,' 1903, Supp. Bd., p. 209; (4) Schaternikoff, 'Archiv f. Physiologie,' 1904, Supp. Bd., p. 135; (5) F. G. Benedict and H. L. Higgins, 'American Journal of Physiology,' 1911, vol. 38, p. 1.

† Rosenthal, 'Archiv f. Physiologie,' 1902, Supp. Bd., p. 293.

‡ Lukjanow, 'Zeits. f. physiol. Chemie,' 1884, Bd. 8, p. 324.

§ "The Nitrogen Content of the Blood," 'Journ. Physiol.,' 1912, vol. 43, No. 6, p. 401.

|| 'Skand. Arch. Physiol.,' 1910, vol. 23, p. 220.

different animals cannot be identical in all respects. C. G. Douglas,* using rabbits as the subject of his experiments and the Gowers-Haldane hæmoglobinometer to determine the percentage oxygen capacity of blood, considers that a parallel relationship exists between the oxygen capacity of the blood and the depth of its colour as judged by the hæmoglobinometer, and it was essential for our purpose to ascertain if this was true for cats.

In the case of cats we have found that there is complete agreement between the actual values for oxygen as determined with our pump and that of the oxygen capacity by the hæmoglobinometer. We used hirudinised blood of cats; the saturation method, determined *in vitro* at 38° C., has been described in a former paper.†

Percentage Oxygen Capacity of Blood.

	By pump.	By hæmoglobinometer.
A	16·52	17·39 hirudin.
B	21·04	19·89 defibrinated blood.
C	19·48	19·89 hirudin.
D	17·24	16·56 „
Mean	18·57	18·43

Difference +0·14 c.c. per 100 c.c. blood.

This supports the contention of those who believe that no valid argument exists against the view that the hæmochromogen moiety of the molecule of hæmoglobin is identical in all animals.

Composition of the Blood Gas for Animals Breathing Air and Oxygen respectively.

In Table I we give for cats under urethane anæsthesia:—

1. The composition of the blood gases.
2. Percentage hæmoglobin value.
3. Calculated theoretical oxygen capacity per 100 grm. of blood.
4. Calculated percentage saturation of hæmoglobin.
5. Calculated percentage saturation of hæmoglobin from the percentage composition of alveolar air, making use of the blood dissociation curve given by J. Barcroft and M. Camis for dog's blood.‡
6. The percentage composition of alveolar air.

* 'Journ. Physiol.,' 1910, vol. 39, p. 453.

† 'Journ. Physiol.,' 1912, vol. 43, No. 6, p. 410. In Experiment XIV, Table III, the second oxygen figure in the blood-gas analysis should read 17·24 instead of 13·59.

‡ 'Journ. Physiol.,' 1909, vol. 39, p. 132.

Table I.—Arterial Blood (Carotid Artery) of Cats Breathing Air.

No. of experiment.	Weight of cat.	Hirudin.	Volume of blood.	Blood gas per 100 c.c. blood.				Percentage of hæmoglobin.	Theoretical oxygen capacity.	Calculated percentage saturation of hæmoglobin.	Calculated percentage saturation of hæmoglobin.*	Alveolar air.			Remarks.
				Total.	CO_2.	O_2.	N.					CO_2.	O.	N.	
	kgrm.		c.c.	c.c.	c.c.	c.c.	c.c.								
I	3·2	+	21·5	50·07	34·52	14·50	1·05								
II	2·7	+	21·44	47·91	33·68	13·10	1·14								
III	2·8	+	10·3	53·80	37·48	15·22	1·12	84	15·54	97·4					
IV	2·5	+	10·3	51·57	35·76	14·89	0·91	84	15·54	95·8	—	5·0	—	—	Respiration frequency 43 per min.
VI	2·7	+	10·3	50·15	33·65	15·29	1·22	92	17·02	89·8	88·0	3·95	13·56	82·47	72 per min. resp. rate.
VII	3·7	+	10·3	50·03	33·09	15·96	0·97	95	17·58	90·8	90·5	2·68	15·23	82·09	Resp. rapid; average 73 per min. just before taking sample.
VIII	2·7	+	10·3	64·71	47·84	15·66	1·22	103	19·15	81·7	86·0	6·24	9·15	84·64	Blood rather dusky, but tracings before and after sample showed lung ventilation not very efficient in depth and frequency; rate 15—16 per min.
IX	1·9	+	10·3	56·26	43·58	11·58	1·09	92	17·02	68	87·2	6·38	11·61	82·01	
X	2·5	—	10·3	51·17	38·08	12·03	1·07	80·5	14·89	80·8	87·0	6·25	9·74	84·04	
XI	—	—	10·3	57·17	38·68	17·45	1·07	105	19·42	89·7	87·5	5·74	9·66	84·59	Shallow, panting respiration.
XII	2·6	+	10·3	60·70	49·48	10·01	1·21	96	17·76	86·3	—	—	—	—	Blood dark. Sample taken 4 hours after urethane.
XIII	2·6	+	10·3	55·54	42·03	12·56	0·95	95	17·57	71·5	—	—	—	—	Same cat as XII, 1 hour later.
XIII *a*	3·3	+	10·3	50·01	31·77	16·68	1·55								
	Mean values ……			53·76	38·43	14·22	—	—	17·15	83	—	—	—	—	

* From curve of dissociation given by Barcroft and Camis.

Table II.—Arterial Blood (Carotid Artery) of Cats Breathing Oxygen.

No. of experiment.	Weight of cat.	Hirudin.	Volume of blood.	Blood gas per 100 c.c. blood.				Hæmoglobin, Gowers-Haldane.	Theoretical oxygen capacity.	Calculated percentage saturation of hæmoglobin.	Alveolar air.			Duration of oxygen.	Remarks.
				Total.	CO_2.	O_2.	N.				CO_2.	O.	N.		
	kgrm.		c.c.	c.c.	c.c.	c.c.	c.c.							mins.	
XVIII	2·2	+	21·5	49·62	38·38	10·78	0·48	72	13·32	80·93	5·80	89·48	4·71	78	
XIX	2·6	+	21·45	67·42	50·08	17·16	0·18	—	—	—	7·58	86·76	5·95	89	
XX	2·2	+	21·5	51·56	40·79	10·60	0·18	—	—	—	19·43	79·86	0·73	77	Respiration shallow and slow.
XXI	3·6	+	21·5	50·77	33·56	17·07	0·12	81·5	15·08	113·4	3·84	94·33	1·81	78	Normal respiration.
XXII	3·0	+	21·5	60·26	41·59	18·28	0·39	85·5	15·82	115·5	8·31	88·84	2·84	84	Normal respiration.
XXIII	2·8	+	10·3	47·71	32·83	14·82	0·06	83	15·26	96·5	—	—	—	72	Irregular and shallow.
XXIV	2·5	+	10·3	47·01	33·09	13·85	0·08	84	15·54	89·15	—	—	—	55	Rapid and somewhat deep respiration.
XXV	2·7	+	10·3	54·98	38·28	16·62	0·07	89	16·46	101·6	4·65	92·77	2·58	48	Rapid and deep.
XXVI	3·7	+	10·3	39·37	26·90	12·30	0·17	94	17·39	70·6	5·00	92·98	2·01	35	Rapid; animal disturbed by retching movements before sample.
XXVII	2·7	+	10·3	64·54	45·65	18·81	0·08	103	19·15	98·24	10·97	86·03	3·00	95	Slow and shallow.
XXVIII	3·3	+	10·3	54·06	37·99	15·99	0·07	—	—	—	—	—	—	77	Normal respiration.
XXIX	2·8	+	21·55	50·84	40·00	10·74	0·10	104·5	19·33	55·50	—	—	—	110	
XXX	3·1	+	21·5	61·01	43·18	17·21	0·12	104	19·24	89·45	8·20	88·88	2·95	108	Ventilation of lung exceedingly good. 1·50 per m., resp. very deep, 28 per m. 1·55 „ „ 40 „ 2·25 „ respiration shallower.
Mean values				53·79	38·65	14·94	—	—	16·67	91·09*					

* Or, by calculation from mean values, 89·62.

In Table II we give similar data with the respiration of oxygen, the samples of blood for analysis and those of alveolar air being taken during the period of oxygen inhalation; the alveolar air *immediately* after the blood sample.

On comparing these two tables, it will be seen that the average blood gases in the two series of experiments are in close accord, indeed practically identical.

Average of Thirteen Experiments on Cats breathing Air and Oxygen.

	Air.	Oxygen.
Total gas	53·76	53·79
Carbon dioxide	38·43	38·65
Oxygen	14·22	14·94

In some experiments blood was abstracted from the same animal when breathing first air and subsequently oxygen.

A contrast of these duplicate samples of arterial blood of animals breathing air and oxygen is given below:—

Air.		Oxygen.	
CO_2.	O_2.	CO_2.	O_2.
47·84	15·66	45·65	18·81
33·09	15·96	26·90	12·30
33·65	15·29	38·28	16·62
35·76	14·89	33·09	13·85
37·48	15·22	32·83	14·82
31·77	16·68	37·99	16·99

It will be seen that, although the percentage of hæmoglobin is practically the same in the same pair of experiments, the oxygen in the blood is sometimes a little greater, sometimes less, when oxygen is inhaled, differences which appear to be independent of the percentage of oxygen in the alveolar air.

The hæmoglobin values in the several experiments are very variable in cats. The theoretical oxygen capacity of cats breathing air, ascertained from 10 experiments in which the hæmoglobin values were determined, was 17·15 c.c. per 100 c.c. of blood. Calculating from the average oxygen found, 14·22, the average percentage saturation of hæmoglobin is about 83.

In the case of animals breathing oxygen, the theoretical oxygen capacity

calculated from 10 experiments is 16·67, giving an average percentage saturation of the hæmoglobin of 89·62; 6·7 per cent. higher than in the case of animals breathing air. But it is noticeable that the average hæmoglobin percentage for cats breathing air is 92·65, and for 10 cats respiring oxygen it is only 90·05. It would seem evident from these experiments that the inhalation of oxygen does not necessarily augment the quantity of oxygen in the blood, nor does it appear to affect the quantity of carbon dioxide.

On reference to Table II it will be seen that the average carbon dioxide-content of arterial blood in 13 experiments was 38·43 c.c. per 100 c.c. of blood, or 70·9 per cent. of the total gas. With animals in a state of hyperpnœa,* this falls to an average of 20·56 c.c. per 100 c.c. of blood, or 58·7 per cent. of the total gas, the oxygen remaining practically the same. In experiments with hirudinised blood *in vitro* the carbon dioxide is only 3·83 c.c. per 100 c.c. of blood, or 16·3 per cent. of the total gas.

	Cats breathing air (average of 13 experiments.	(1) Cats in state of hyperpnœa (average of four experiments).*	(2) Blood shaken in air until saturated with oxygen (average of four experiments).†
Total gas	53·76	35·02	23·45
CO_2	38·43	20·56	3·83
O_2	14·22	13·50	18·57

The oxygen-content is of some importance. In Table II the average oxygen-content per 100 grm. of blood in 14 experiments is 14·22 c.c. In the various experiments the values vary considerably, from 10 c.c. to 17 c.c., and the percentage saturation of hæmoglobin is also variable, the average being 83 to 84 per cent. In the cats in a state of hyperpnœa the average is 13·5 not very different from many of the values found in quiet respiration. It would appear from our experiments that the state of hyperpnœa affects the carbon dioxide output rather than the oxygen intake. From the experiments we have already published, it is clear that it takes a considerable time for blood *in vitro* to become saturated with oxygen at 38° C., when exposed to air.

From these experiments it is a fair conclusion that during its passage through the pulmonary capillaries the blood is rarely fully saturated with oxygen even when oxygen is inhaled. For an explanation, it is probable

* 'Journ. Physiol.,' 1910, vol. 41, p. 61.

† 'Journ. Physiol.,' 1912, vol. 43, No. 6, Table III, p. 410.

that parts of the lung, for example the apices, are imperfectly ventilated, and also, since the circulation time in the lung is only about five or six seconds, that complete equilibrium is not attained between the blood and alveolar air.

In the case of venous blood, we have only made one experiment in a cat breathing air.

Venous Blood.

Weight of cat.	Hirudin.	Volume of blood.	Total gas.	CO_2.	O_2.	N.
3·7	+	c.c. 21·5	56·66	44·24	11·31	1·12

We have, however, made a number of determinations of the gases of human venous blood. This was withdrawn from the median basilic vein by displacement of mercury in the manner described in detail in a former paper.* As we performed the experiments on ourselves, the blood was not hirudinised and was taken without an anæsthetic. The results are given in Table III.

Table III.—Venous Blood (Human). Air.

No. of experiment.	Source of blood.	Sample of blood.	Gas per 100 grm. blood.				Remarks.
			Total.	CO_2.	O_2.	N.	
		c.c.	c.c.	c.c.	c.c.	c.c.	
A	J. A. G.	21·37	55·59	44·05	10·27	1·27	No bandage round forearm. Early form of new pump.
B	G. A. B.	18·7	61·46	50·95	9·02	1·47	No bandage on forearm. Early form of new pump.
C	J. A. G.	21·5	54·58	49·07	3·39	2·11	,, ,, ,,
D	G. A. B.	21·5	59·94	53·33	4·80	1·82	,, ,, ,,
E	J. A. G.	21·4	55·04	47·10	5·56	2·40	,, ,, ,,
F	,,	21·45	53·39	41·14	10·80	1·47	,, ,, ,,
G	G. A. B.	21·1	63·22	52·47	9·10	1·65	Taken without any straining of muscles, but after some exercise. Early form of new pump.
H	,,	16·5	57·89	48·44	7·79	1·64	Early form of new pump.
I	,,	19·0	58·56	46·31	10·21	2·05	,, ,, ,,
J	J. A. G.	10·3	57·17	50·73	5·37	1·07	Bandage on forearm, not uncomfortably tight. New pump; vacuum with liquid air.
K	,,	10·3	57·19	53·63	2·63	0·96	Bandage on forearm, a little tighter. New pump; vacuum with liquid air.

* 'Journ. Physiol.,' 1910, vol. 40, p. 373.

Table IV.—Venous Blood of Cats Breathing Oxygen.

No. of experiment.	Weight of cat.	Hirudin.	Volume of blood.	Blood gas per 100 c.c. blood.				Hæmoglobin.	Calculated percentage saturation of hæmoglobin.	Theoretical oxygen capacity.	Alveolar air.			Source of blood.	Duration of oxygen.	Remarks.
				Total.	CO_2.	O_2.	N.				CO_2.	O_2.	N.			
	kgrm.		c.c.	c.c.	c.c.	c.c.	c.c.								mins.	
XXXI	3 ·2	+	21 ·2	39 ·77	35 ·93	3 ·59	0 ·26	—	—	—	—	—	—	Right heart ...	80	
XXXII	3 ·0	+	20 ·8	49 ·90	43 ·90	5 ·71	0 ·28	—	—	—	—	—	—	Inferior vena cava	120	
XXXIII	3 ·5	+	21 ·45	58 ·99	51 ·24	7 ·39	0 ·36	—	—	—	7 ·21	88 ·00	4 ·8	Inferior vena cava	95	Cannula slipped for a moment from trachea 15 mins. before sample of blood taken.
XXXIV	2 ·2	+	21 ·45	67 ·70	53 ·89	13 ·49	0 ·33	—	—	—	10 ·71	87 ·04	2 ·25	Right jugular into heart	55	
XXXV	2 ·4	—	21 ·5	61 ·86	51 ·39	10 ·11	0 ·35	—	—	—	9 ·08	88 ·06	2 ·86	Right jugular into heart	124	Very steady good respiration.
XXXV*a*	—	—	—	78 ·22	47 ·27	8 ·06	0 ·31	—	—	—	9 ·00	87 ·7	3 ·30			
XXXVI	3 ·3		21 ·5	80 ·15	71 ·55	8 ·02	0 ·58	94 ·5	17 ·54	45 ·7	34 ·86	60 ·12	5 ·03	Inferior vena cava	130	Respiration, 40 per min. Some mucus in trachea, gurgling breathing, slow and shallow.

The first nine experiments were made some time ago, without the precautions we have insisted upon as being necessary in the use of the blood pump, and the nitrogen values are above the true value. The last two experiments given in Table III were carried out with all precautions, the pump washed out with oxygen, and rendered vacuous with liquid air, and *it will be seen that the nitrogen values are* 1·07 *and* 0·96 *per cent. of blood respectively;* figures exactly the same as those which we found for the nitrogen-content of cat's blood.*

The oxygen-content of venous blood is seen to vary from 2·63 c.c. to 10·8 c.c. per 100 c.c. of blood.

In Table IV we give the values of venous blood of cats breathing oxygen. The oxygen figures vary from 3·5 c.c. to 13·49 c.c. per 100 c.c. of blood, and are of much the same order as during the respiration of air.

Conclusions.

The experiments detailed in this paper would appear to justify the following conclusions:—

1. The inhalation of oxygen does not materially augment the quantity of this gas in the blood.

2. The inhalation of oxygen apparently does not alter the average carbon dioxide content of the blood.

We are carrying out further experiments on the inhalation of oxygen, with a view to testing the validity of the above conclusions.

We take this opportunity of thanking the Committee of the Government Grant of the Royal Society for assistance in partly defraying the expenses connected with this work.

* 'Journ. Physiol.,' 1910, vol. 41, p. 61.