PHILOSOPHICAL TRANSACTIONS.

I. *A Chemical Inquiry into the Phenomena of Human Respiration.*

By WILLIAM MARCET, *M.D., F.R.S.*

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[PLATES 1, 2.]

A LOVE of mountaineering is a natural inducement to inquire into the influence of altitude on the phenomena of respiration, and I began giving attention to that subject in 1875; my first results, however, were not communicated to the Royal Society till the month of March, 1878. In September, 1877, Dr. A. MERMOD, then Mr. MERMOD, had contributed to the "Bulletin de la Société Vaudoise des Sciences Naturelles," an interesting paper on this same subject, which he had treated in its chemical aspect, much in the same way as I had done. The title of his paper is "Nouvelles recherches physiologiques sur l'influence de la dépression atmosphérique sur l'habitant des montagnes." The following are the conclusions he arrives at:—

(1.) The uninterrupted and prolonged stay at increasing altitudes is attended with a greater frequency of the pulse.

(2.) The uninterrupted and prolonged stay at 1100 metres above the sea level is not attended with any acceleration of the respiratory movements.

From these two laws the author concludes that—

(3.) The mean fraction showing the relation between the respiratory frequency and the pulsations of the heart, becomes smaller and smaller on removing to stations increasing in altitude.

(4.) The temperature of the body does not appear markedly diminished by removing from a dwelling at 142 metres to another at 1100 metres.

(5.) Instead of an increase, there is rather a reduction in the weight of the air breathed by removing higher and higher above the sea level.

(6.) The absolute and relative quantity of carbonic acid exhaled from the lungs increases by removing into higher regions, although there be no change in the respiratory frequency ; at the same time the weight of the air breathed is reduced.

Dr. MERMOD's investigations were undertaken at two stations only, one of them being Strasburg, at an altitude of 142 metres, and the other Ste. Croix, at 1100 metres; the difference of altitude amounting therefore to the small figure of 958 metres. Thirty-five experiments were made at Strasburg, and thirty-two at Ste. Croix, on the volumes of air breathed and weights of carbonic acid expired. The mean barometric pressure was 744·89 mm. at Strasburg, and 669·21 mm. at Ste. Croix, giving a difference of 75·68 mm. The extent of the inquiry appears hardly sufficient to determine the influence of atmospheric pressure on the chemical phenomena of respiration, but the work is evidently well done, and I feel called upon to discuss it in some of its bearings.

On one point I agree with Dr. MERMOD, that there is a reduction in the weight of air breathed within a given time at increasing altitudes, and depending on atmospheric pressure alone. My experiments, which extend to altitudes of 3300 and 4000 metres, some of them made under circumstances doing away with the influence of cold, certainly yield that result. I have expressed this law by stating that there is, at increasing altitudes, a reduction in the volume of air breathed, reduced to 0° and 760 mm.

Dr. MERMOD's sixth and last conclusion deals with the amount of carbonic acid exhaled from the lungs within a given time at different altitudes. At first I was disposed to conclude with him, that more carbonic acid is expired as the atmospheric pressure falls from increasing altitude, as I found that more carbonic acid was exhaled per minute in the mountains than in the plains; but it occurred to me that the increased cold experienced on ascending in the Alps was not unlikely to exert an influence on this phenomenon, and that the excess of carbonic acid expired in Alpine districts might be due to *cold* and not to *rarefied air*. My experiments, made on the peak of Tenerife, in order to clear up this point, showed conclusively that when no cold is experienced on reaching higher levels, there is no increase in the amount of carbonic acid expired within a given time.

Dr. MERMOD does not lose sight of the question of temperature, as he records the temperature of the atmosphere at the time of every experiment, and he finds that the mean of all the temperatures observed was the same at both stations. At his lower station, his mean temperature is 12°·65 C., and at his higher station, 12°·68 C. He thus disposes of any influence due to differences of temperature. The effect of food is done away with by making the experiments between 7 and 8 o'clock in the morning, and before breakfast. The barometer reading is recorded at the time of every experiment, but it is much to be regretted that the author quotes no hygrometric observations.

By considering together the temperatures of the air when the different experiments were made, and corresponding weights of carbonic acid expired, as stated in Dr. MERMOD's Tables, a very remarkable influence of the temperature at the higher station will be found. In order to show this, I have extracted from Dr. MERMOD's paper, and placed opposite each other in a tabular form, the mean weights of carbonic acid expired at both stations for each degree of temperature—from 9° to 10°, 10° to 11°, and so on :—

Temperatures at time of experiment.	Strasburg. CO_2 expired per minute.	Ste. Croix. CO_2 expired per minute.	Increase for Ste. Croix.	
			Per cent.	
9° to 10°	0·392	0·387	0·0	mean 3·1
10 „ 11	0·394	0·419	6·0	
11 „ 12	0·388	0·401	3·2	
12 „ 13	0·374	0·397	5·8	mean 7·0
13 „ 14	0·373	0·393	5·1	
14 „ 15	0·371	0·413	10·2	

First of all we observe that, as the temperature increases at the lower station, the weight of carbonic acid expired per minute as a rule falls, while at the higher station the weight of carbonic acid expired per minute is nearly the same at every temperature.

If, on the other hand, the weights of carbonic acid expired at Strasburg and Ste. Croix be compared with each other *for similar temperatures*, we find no increase of carbonic acid at Ste. Croix for the lowest temperature (9° to 10°), although a considerable increase, amounting to 10·2 per cent., at the highest temperature. By collecting the temperatures and corresponding weights of carbonic acid into two groups, the group for the lowest temperatures will give an increase of carbonic acid of only 3·1 per cent. for Ste. Croix (the highest station), while the group for the highest temperatures will show an excess of carbonic acid of 7·0 per cent. for that same station.

The analysis of the tables in another form yields a similar conclusion. I have disposed as follows the figures for carbonic acid corresponding to the ten lowest and ten highest temperatures for each station :—

Strasburg.				Ste. Croix.			
Ten lowest temperatures.		Ten highest temperatures.		Ten lowest temperatures.		Ten highest temperatures.	
Temperatures.	CO_2.	Temperatures.	CO_2.	Temperatures.	CO_2.	Temperatures.	CO_2.
° 9·50	0·393	° 15·60	0·354	° 8·75	0·393	° 16·00	0·387
9·60	0·413	15·40	0·342	9·00	0·385	16·00	0·447
9·60	0·370	14·20	0·396	9·30	0·391	15·90	0·412
10·00	0·390	14·00	0·350	9·40	0·422	15·90	0·376
10·50	0·390	13·80	0·358	9·50	0·388	15·90	0·423
10·80	0·396	13·80	0·377	9·50	0·374	15·80	0·413
10·90	0·398	13·70	0·348	9·55	0·374	15·50	0·404
11·20	0·394	13·50	0·379	9·90	0·394	15·30	0·386
11·20	0·382	13·40	0·361	10·10	0·418	14·90	0·427
12·60	0·390	13·40	0·358	10·30	0·421	14·50	0·391
Mean 10·59	0·392	14·08	0·362	9·53	0·396	15·57	0·406

It follows from this Table that the experiments made at the ten lowest temperatures at Strasburg yield an increase of carbonic acid of 7·6 per cent. over the experiments made at the ten highest temperatures. This is just what might have been expected from the effect of the cold. At Ste. Croix, however, the conclusion is very different, as at that station there is a slight excess of 2·4 per cent. carbonic acid for the experiments made at the highest temperature over the mean carbonic acid found at the lowest temperatures at that same station. Moreover, if we compare with each other the mean weights of carbonic acid expired at the ten lowest temperatures for the two stations, they will be found nearly exactly the same (0·392 and 0·396), while for the ten highest temperatures there is much more carbonic acid expired at Ste. Croix than at Strasburg (0·406 and 0·362), the increase being by no less than 10·8 per cent. This appears at first sight quite unaccountable, although I think it can be satisfactorily explained.

There was clearly some influence on the experiments at Ste. Croix connected with the highest temperatures which was absent at Strasburg. That influence I believe to be a lower state of relative humidity of the air, which, by producing increased perspiration and increased evaporation at the lungs, exerted a cooling action on the body, thus necessitating an increase of animal combustion. It is true that the atmosphere was warmer, but this circumstance failed to compensate for the cold produced by increased perspiration and evaporation.

This explanation appears to me to account satisfactorily for the increase of carbonic acid observed at the higher station: it was not due to the fall of atmospheric pressure, but to increased dryness of the atmosphere, acting precisely in the same way as an accession of cold would have done.

Before entering any further upon this communication I must beg to acknowledge the valuable aid of my assistant, Mr. C. F. TOWNSEND, F.C.S., to whose diligent, methodical, and careful work I am greatly indebted for the results obtained in the present inquiry. We made together the numerous calculations for the reductions, thus checking the figures in every possible way to insure accuracy.

Since my attention was first given to the chemical phenomena of respiration, I have had the honour of communicating to the Royal Society a succession of papers on the "Influence of Altitude on Respiration," which have appeared in volumes 27, 28, 29, and 31 of the 'Proceedings.' These inquiries show in the most conclusive manner that altitude exerts an action on respiration depending exclusively on the fall of atmospheric pressure, and the law can be expressed as follows:—"The volumes of air breathed, reduced to 0° and 760 mm., in order to produce a certain weight, say, 1 gramme of carbonic acid in the body, are smaller on mountains under diminished atmospheric pressures than they are in the plains under higher pressures." My earliest experiments on the Breithorn (13,685 feet—4171 metres), the Col St. Théodule (10,899 feet—3322 metres), the Riffel (8428 feet—2568 metres), the St. Bernard (8115 feet—2473 metres), and the Col du Géant (11,030 feet—3362 metres) were all attended with a fall of the atmospheric temperature on reaching into higher altitudes; this circumstance necessarily produced an increased combustion in the body in order to overcome the action of the cold, and introduced an element into the inquiry which was likely to interfere with the exclusive influence altitude might exert on the chemical phenomena of respiration. The only way of overcoming this difficulty was to resort to a mountain where it was possible to ascend to a considerable altitude without meeting with the cold air of northern Alpine districts. Thus I was induced to visit the Peak of Tenerife, taking with me the instruments required to repeat the experiments undertaken in the Swiss Alps. I spent three weeks on the Peak in the summer of 1878, engaged in these inquiries. The temperature, though varying somewhat at the three stations I had selected at various altitudes, was always hot in the daytime, and there was no cause for any increased formation of carbonic acid in the body towards the resistance of cold. The result was most striking. While in the cold Swiss Alps I had observed an increased expiration of carbonic acid when ascending on myself and others who submitted to the experiment, on the Peak of Tenerife there was no such increase. The mean weight of carbonic acid expired at the three stations by two different persons was, with one exception at one station only—in the case of a Chamonix guide—nearly the same for each of them respectively; the volumes of air breathed were lessened,* so that the law remained unchanged: that at increasing alti-

* There is one exception in the case of the Chamonix guide, the volume of air he expired (for 1 grm. CO_2) being somewhat greater at the higher than the intermediate station on the Peak; but the mean volume of air expired at these two stations, taken collectively, was much less than the mean volume of air expired at the seaside.

tudes less air breathed, reduced to 0° and 760 mm., than at the sea level, is required to produce 1 grm. of carbonic acid in the body. The experiments on the Peak of Tenerife, by doing away entirely with the influence of cold, placed this fact beyond doubt.

As it is important towards a clear understanding of this paper that the results obtained formerly should be present to the reader, I beg to subjoin them in a tabular form.

EXPERIMENTS on the Influence of Altitude upon the Chemical Phenomena of Respiration (on Myself).

Stations.	Altitude.	Weight of CO_2 expired.	Litres of air expired reduced to 0° and 760 mm.
	feet.	grm.	
Near Geneva	1,230	1	13·6
St. Bernard	8,115	1	Mean at and above
Riffel	8,428	1	8115 feet up to
Col St. Théodule	10,899	1	13,685 feet.
Summit of Breithorn	13,685	1	11·05

ON the Peak of Tenerife (on Myself).

Stations.	Altitude.	Weight of CO_2 expired.	Litres of air expired reduced to 0° and 760 mm.
	feet.	grm.	
Seaside	..	1	12·24
Guajara	7,090	1	11·9
Alta-Vista	10,700	1	10·7
Foot of terminal cone	11,740	1	10·6

COL du Géant (on Myself).

Stations.	Altitude.	Weight of CO_2 expired.	Litres of air expired reduced to 0° and 760 mm.
	feet.	grm.	
Near Geneva	1,230	1	15·5 Mean before and after ascent.
Courmayeur	3,945	1	14·35
Summit of Col du Géant	11,030	1	12·6

COL du Géant (on a Companion).

Stations.	Altitude.	Weight of CO_2 expired.	Litres of air expired reduced to 0° and 760 mm.
	feet.	grm.	
Geneva	1,230	1	13·7 Mean before and after ascent.
Courmayeur	3,945	1	14·8
Summit of Col du Géant	11,030	1	12·6

The experiments were made by determining as carefully as possible the volume of air expired within a given time, and finding the amount of carbonic acid this air contained by means of PETTENKOFER'S method carried out with the aid of an instrument I had constructed for that purpose. Then, knowing the weight of carbonic acid in a given volume of air, it was easy to find, by a very simple calculation, the volume of air (reduced to 0° and 760 mm. pressure) corresponding to, or holding, 1 grm. of carbonic acid. The method and instruments employed in this inquiry have been fully described in a previous communication.

Being desirous of ascertaining whether at such stations as those frequented by invalids the same effects were produced on the function of respiration as at greater elevations, I repeated the experiment in the year 1882 on the Rigi Mountain, in Switzerland, in the company of a young engineer, Mr. R. THURY. As the results obtained have never been published, beyond a short reference to them in a paper to the Alpine Club, I shall beg to include a tabular statement of these experiments in the present communication. The inquiry made on the Rigi confirms in every way the law ruling the chemical phenomena of respiration at different altitudes. Mr. THURY submitted alone to these experiments.

Fifteen experiments were made on the 3rd and 4th of September near Geneva, at an altitude of 1230 feet (375 metres), mean barometer pressure of 728 mm. and temperature of 15°·9 C.; and eighteen experiments were made as soon as possible afterwards at the Rigi Staffel, at a mean pressure of 639 mm. and mean temperature of 7°·6 C. during the experiments. The Rigi Staffel is situated at an elevation of 5230 feet (1594 metres), giving a difference of altitude of 4000 feet, or 1219 metres, and of 89 mm. mean pressure, between the two stations. It might have been expected that more carbonic acid would be exhaled in a given time on the cold mountain station than in the valley of Geneva, and this turned out to be the case; as, while a mean of 0·350 grm. CO_2 was expired near Geneva the lower and warmer station, this figure rose to a mean of 0·445 grm. at the higher or colder station—giving an excess of no less than 21 per cent. of carbonic acid for the Rigi. The amount of air expired, say breathed, for the expiration of 1 grm. of carbonic acid, reduced to 0° and 760 mm., was 10·78 litres in the Geneva valley, and only 9·45 litres on the Rigi station. Therefore, for a mean difference of 89 mm. atmospheric pressure (including the influence of reduced temperature), less air by 12 per cent. was breathed on the mountain to supply the oxygen required by the body to burn the same amount of carbon as in the valley.

EXPERIMENTS at Malagny, near Geneva, on Mr. R. THURY, 1883. Barometer = 728 mm.

Number.	Date.	Time with reference to food taken.	Temperature of air.	Grammes of CO_2 expired per minute.	Litres of air expired per minute (reduced).	Litres of air expired (reduced) corresponding to 1 grm. CO_2.	Percentage volume of CO_2 in air expired.
		h. m.	° C.				
1	Sept. 3	2 10 after lunch . .	20·0	·334	3·65	10·93	4·66
2	,,	3 25 ,, ,, . .	18·5	·319	3·40	10·65	4·77
3	,,	3 55 ,, ,, . .	17·5	·303	3·29	10·88	4·67
4	,,	4 40 ,, ,, . .	16·5	·343	3·60	10·48	4·85
5	,,	5 20 ,, ,, . .	15·0	·294	3·17	10·77	4·72
6	Sept. 4	0 45 after breakfast .	16·0	·358	3·99	11·12	4·57
7	,,	1 30 ,, ,, .	16·5	·401	4·52	11·29	4·50
8	,,	2 25 ,, ,, .	16·0	·418	4·53	10·84	4·69
9	,,	3 0 ,, ,, .	15·0	·374	4·17	11·17	4·55
10	,,	0 45 after lunch . .	14·5	·410	4·40	10·75	4·73
11	,,	1 15 ,, ,, . .	15·0	·359	3·86	10·75	4·73
12	,,	2 10 ,, ,, . .	15·0	·340	3·49	10·28	4·94
13	,,	2 50 ,, ,, . .	14·5	·305	3·34	10·94	4·64
14	,,	4 0 ,, ,, . .	14·0	·366	3·82	10·42	4·88
15	,,	4 55 ,, ,, . .	14·0	·329	3·45	10·47	4·85
		2 52 mean time after a meal	15·9 mean	·350 mean	3·78 mean	10·78 mean	4·72 mean

EXPERIMENTS at the Rigi Staffel on Mr. THURY, 1883. Barometer = 639 mm.

Number	Date.	Time with reference to food taken.	Temperature of air.	Grammes of CO_2 expired per minute.	Litres of air expired per minute (reduced).	Litres of air expired (reduced) corresponding to 1 grm. CO_2.	Percentage volume of CO_2 in air expired.
		h. m.	° C.				
1	Sept. 7	1 45 after lunch . .	9·0	·332	3·23	9·72	5·23
2	,,	2 30 ,, ,, . .	9·5	·326	3·24	9·94	5·11
3	,,	3 10 ,, ,, . .	10·0	·364	3·51	9·64	5·27
4	,,	3 55 ,, ,, . .	7·5	·379	3·61	9·54	5·32
5	,,	4 40 ,, ,, . .	7·5	·451	4·08	9·05	5·61
6	,,	5 15 ,, ,, . .	7·5	·416	3·93	9·44	5·38
7	Sept. 9	1 30 ,, ,, . .	8·0	·454	4·23	9·30	5·46
8	,,	2 22 ,, ,, . .	9·0	·533	4·60	8·62	5·89
9	,,	3 5 ,, ,, . .	6·0	·382	3·79	9·93	5·12
10	,,	3 50 ,, ,, . .	6·0	·453	4·22	9·32	5·45
11	,,	4 27 ,, ,, . .	5·0	·488	4·44	9·11	5·58
12	Sept. 10	0 35 after breakfast .	6·5	·503	4·48	8·92	5·70
13	,,	1 8 ,, ,, .	7·0	·532	4·98	9·37	5·42
14	,,	1 48 ,, ,, .	8·0	·511	4·85	9·49	5·35
15	,,	2 33 ,, ,, .	6·0	·511	5·00	9·48	5·36
16	,,	3 30 ,, ,, .	7·5	·491	4·94	10·06	5·05
17	,,	4 25 no lunch . . .	8·5	·444	4·40	9·92	5·12
18	,,	5 30 ,, ,, . . .	8·5	·442	4·55	10·28	4·94
		3 7 mean time after a meal	7·6 mean	·445 mean	4·23 mean	9·45 mean	5·35 mean

The following investigation was carried out in a laboratory of the Physiological Department at University College, which Professor SCHÄFER has kindly placed at my disposal. Two persons—my assistant, Mr. C. F. TOWNSEND, and my laboratory attendant, WILLIAM ALDERWOOD, who has worked for the last five years in my laboratory, and whom I can thoroughly trust to carry out my instructions—both kindly submitted to experiment.

The inquiry has to be prefaced with a statement of the method of investigation adopted. The main objects were to collect and measure the air expired from the lungs within a given time, and then find out, as accurately as possible, the weight or volume of carbonic acid it contained. I had proposed at first to determine also the volume of air inspired, but met with so many difficulties in carrying this out satisfactorily that it was given up. There are two possible sources of error in a work of this kind, first on account of the resistance breathing has to overcome when the expired air is either collected for analysis or passed through absorbing media; and, secondly, from the attention of the person who is breathing being directed to the experiment, so that respiration becomes a voluntary act instead of being purely automatic. In EDWARD SMITH's experiments* the air was inspired through a dry gas meter, and expired through a succession of vessels which absorbed the water and carbonic acid, the latter being estimated by weighing. This method, although possessed of the advantage of allowing each experiment to be continued for an indefinite length of time, appeared to me hardly delicate enough for the object I had in view, especially because of the unavoidable resistance to free respiration, although it might be but slight. The air expired had therefore to be collected in a bell-jar, in such a way that the person under experiment might not be aware, at the time, that he was breathing with an object in view. I had two bell-jars constructed for this purpose by Messrs. W. PARKINSON and Co., engineers, by whom they were admirably made. Each bell-jar could hold 40 litres of air, and was graduated on a scale into litres and fractions of litres. They were made of japanned iron, and suspended over tanks filled with a solution of pure sodium chloride; the solution in the tank used for most of the experiments had a density of 1·074, corresponding to 10 per cent. of sodium chloride. The tanks had an annular form, so that the fluid should expose as small a surface as possible to the air contained in the jars. The bell-jars were counterpoised over a pulley fixed to a cycloid to which another regulating weight was suspended.

The cycloid was so constructed that the increased leverage of the regulating weight counterbalanced exactly the increase of weight of the bell-jar as it ascended from the tank and *vice versâ*. A gauge fixed to the dome of the bell-jar and charged with almond oil indicated the state of tension of the air in the jar. I found that by keeping the outside of the bell-jars carefully lubricated with almond oil their motion through the salt water was certainly facilitated, and after careful adjustment the bell-jars were so nicely suspended that air could be expired quite unconsciously into them through a

* 'Phil. Trans.,' 1859.

pipe about an inch in diameter, opening under the dome of the bell-jar. But this still proved insufficient, as it was necessary to devise some method enabling the person under experiment to breathe without his being aware that his breath was being collected for experiment. The difficulty was overcome as follows :—A double-way stop-cock, with passages not much less than an inch in diameter, was fixed to an upright stand screwed to the floor, and an india-rubber tubing of a corresponding diameter was connected with it, long enough to be used by a person sitting in a recumbent posture in a deck chair—there was a vulcanite mouthpiece in the distal end of the india-rubber tube. By means of a handle the double-way cock could be turned in such a position as to enable the person sitting in the deck chair to breathe either into the open air or into the bell-jar. A little silk flag placed inside a glass tube introduced in the course of the india-rubber tubing, flapped during the expiration and remained still while air was inspired, thus acting as a guide throughout the experiment. This arrangement answered the purpose in every way ; the person experimented upon was instructed to inspire through the nose and expire through the tube while in communication with the open air, and without paying any attention to the bell-jar, the little flag showing clearly the time when the respiration had become perfectly slow and natural. Then, without giving any notice and unknown to the person under experiment the handle of the double way cock was turned during an inspiration and the expired air directed towards the bell-jar ; this was so delicately suspended that no appreciable difference of sensation was experienced in the breathing, and it frequently happened that the bell-jar was half way up while the person in the chair still thought he was breathing into the outside air. In order to deviate in no way from natural respiration in these experiments, no valvular face-piece was used, the air, as stated above, being inspired through the nose and expired through the mouth. A little practice made it quite easy, but in order to ensure absolute accuracy the two persons who submitted to experiment closed their nose during expiration by a light pressure with the index finger of each hand held in such a position as to do this with as little effort as possible. After a time the movement became quite automatic, and it was too slight to cause the addition of any appreciable amount of carbonic acid in the expired air.

The experiment was made in the following way :—The person sat in a semi-recumbent posture in a comfortable deck chair, his body and legs being thoroughly supported and the feet resting on a stool at the same height as the legs, thus every muscular strain was done away with. Then he began inspiring through the nose and expiring from the mouth through the india-rubber tube and double-way cock into the open air ; at first the little flag in the track of the air expired was seen to fly about wildly, then by degrees its movements became more regular, and after from ten minutes to a quarter of an hour the respirations were observed to be quite quiet and steady. The scale of the bell-jar being at 0° the stop cock was turned during an inspiration, and the air expired directed into the bell-jar. The instant the bell-jar

commenced rising a stopwatch or chronograph was started, which registered minutes and seconds only. After about 35 litres of air had been collected the watch was stopped at the end of an expiration, and the stop-cock, turned during the next inspiration, the air expired being diverted into the external air. The volume of air collected was read off on the scale, exactly under atmospheric pressure. In some few instances the air was analysed at once (in which case care was taken to rinse out the bell-jar previously with expired air), but as a rule the bell-jar was filled twice or three times so as to obtain two experiments yielding as near as possible the same volume of air expired in a given time. In many cases the difference did not exceed two or three per cent., but it occasionally happened to be much greater. These occurrences were perplexing, and led to careful discussions before the figures were accepted. The air collected in the bell-jar was next submitted to analysis, but first of all its temperature was observed with a thermometer introduced *in situ* through the bell-jar, then the barometer was read.*

The determination of carbonic acid in expired air and atmospheric air has taken up my attention for many years, and after trying various forms of volumetric methods, in which volumes varying from 1 to 7 litres of air expired were submitted to analysis, I finally fell back upon PETTENKOFER's method with which I was well acquainted and which was known to yield reliable results, while simple and speedy in its manipulations. It was necessary to collect the air from the bell-jar into a vessel of the proper shape and size, and agitate this air with a solution of barium hydrate of known strength. The vessel is a cylinder made of strong glass of a capacity of 1 litre, it is closed at both ends by brass caps, screwed over a brass flange cemented to the ends of the cylinder, washers are interposed at the points of contact so as to make the cylinder absolutely air-tight, a brass tube with a stop-cock is soldered to each cap. One of the tubes is widened out and fitted with a thread, so as to screw to a brass piece fixed to a bottle of a capacity of a little over 100 c.c.; the connection being secured air-tight with a washer (a drawing of the instrument is given on Plate 2), the bottle is closed by a wide brass cap screwing upon it perfectly air-tight, so that the bottle can be readily washed out and dried with a towel. The air is drawn from the bell-jar into the dry glass cylinder by means of a pump, the cylinder being first exhausted and then filled with the air from the bell-jar. The operation is repeated eight or ten times, when a weight being placed on the bell-jar 10 or 12 litres more of expired air are driven through the cylinder, which is closed by turning the tap while the air is in transit. Next, the cylinder still attached by india-rubber tubing to the pipe leading from the bell-jar is immersed in water held in a cylindrical tin vessel

* An experiment is quoted here in the abstract of this paper ('Proceedings,' vol. 46, p. 344), towards testing the accuracy of the method of breathing in the bell-jars. It was found subsequently, on repeating it a large number of times, that the results obtained varied to such an extent, from some cause connected exclusively with the experiment, as to make it useless with reference to the object in view. Hence it is omitted on the present occasion.

and the temperature of the water is recorded, corresponding to the temperature of the air to be analysed, the barometer is again read off. This, of course, is done after removing the weights from the bell-jar, and with the air in the bell-jar exactly under atmospheric pressure. Thus 1 litre of saturated air at a given temperature and under a known barometric pressure was obtained for analysis. The analysis was made by taking up 100 c.c. of the normal barium solution with a pipette and introducing it into the bottle, which was next screwed upon the cylinder and tightened with gas pliers. Then the stop-cock closing the cylinder next to the bottle was opened, and by turning the cylinder upside down the alkaline fluid was run into it from the bottle, when on shaking, the solution at once turned milky.

A number of experiments were made to find out how long the agitation of the cylinder had to be continued to ensure the complete combination of the carbonic acid. The experiments were performed both qualitatively and quantitatively. The qualitative test was made by shaking the air with the alkaline solution for a definite time, then aspiring this same air into a second similar cylinder in which a vacuum had been made, the displacement being effected over water. This air was tested for carbonic acid by shaking it with clear baryta water.

After agitating for 10 and 20 minutes the presence of carbonic acid in the second cylinder was still obvious, but after 30 minutes none was left, the solution of barium remaining perfectly clear after brisk agitation.

The quantitative experiment was made by determining the amount of carbonic acid absorbed by the barium hydrate from 1000 c.c. of the same stock of expired air after agitating the cylinder during 20 minutes, 30 minutes, or 40 minutes. The following results were obtained:—

After 20 minutes' agitation.	CO_2 4·130	per cent.	in air expired.
,, 30 minutes' ,, ...	,, 4·194	,,	,,
,, 40 minutes' ,, ...	,, 4·183	,,	,,

Therefore, after 20 minutes, there still remained a small portion of CO_2 unabsorbed; the very slight difference between the results obtained after 30 and 40 minutes is within the probable error of the analyses. As half an hour's agitation was objectionable from the length of time, experiments were made to ascertain whether this period could not be shortened by determining the CO_2 in the cylinder under a pressure exceeding that of the atmosphere.

For this purpose a cylinder was used into which a round graduated brass plunger was introduced—an instrument I had experimented with for some time while searching for a good volumetric method of estimating CO_2. The plunger moving through a close-fitting stuffing box was found to be quite air tight, and by depressing or raising it the pressure in the cylinder could be increased or decreased by the volume of the plunger introduced or withdrawn.

By this means the agitation could be made at will, either below the atmospheric pressure, at that pressure, or above it.

On depressing the plunger to 50 c.c. the air after complete combination was very nearly under atmospheric pressure. On depressing the plunger to 100 c.c. the pressure amounted to very nearly 38 mm. of mercury. On depressing it to 80 c.c. the pressure amounted to nearly 23 mm. of mercury.

It was found that the combination took place much more rapidly at a pressure exceeding that of the atmosphere than below or at the atmospheric pressure.

In ordinary circumstances the absorption of 50 c.c. in the cylinder, from expired air under analysis, would cause a vacuum or fall of pressure of about 38 mm. of mercury. This circumstance militates strongly against complete absorption, but by increasing the pressure as stated above to 23 mm. over and above the atmospheric pressure (after absorption), it was found that after agitating for 10 minutes no CO_2 was left uncombined, and with a pressure of 38 to 40 mm. the combination appeared complete after agitating for 5 minutes.

In the course of the present inquiry the use of the plunger was given up,* and the air in the cylinder was compressed by driving into it about 100 c.c. of common air, free from carbonic acid. This was done with a pear-shaped vulcanised india-rubber bag attached to the end of one of the terminal tubes, as shown in the accompanying drawing. The air was forced into the cylinder with the hand, the stopcock again closed and the bag removed. Thus, a volume of about 100 c.c. of air, free from CO_2 (passed through pumice stone moistened with potassium hydrate), was introduced into the cylinder, producing after combination a pressure of about 38 mm. of mercury. After shaking for a quarter of an hour, the bottle containing the milky alkaline solution was unscrewed from the cylinder and its contents were rapidly poured into a dry glass-stoppered bottle of a capacity of about 100 c.c., which was sealed with paraffin. The next day the precipitate had separated, and the clear fluid was titrated with a solution of oxalic acid of such a strength that 1 c.c. corresponded to 0·001 mgr. CO_2.

Fourteen experiments were undertaken to test the accuracy of this analytical method. In each experiment two analyses were made from the same stock of air in the bell-jar, and the accuracy of the results goes far to show how well the bell-jar retained its equilibrium with the atmospheric pressure. The results are tabulated as follows :—

* Some determinations of CO_2, made with the plunger, by PETTENKOFER's method, have required a small correction owing to the plunger coming out slightly greasy from the stuffing box. A number of experiments showed the correction to amount to a mean of 1 per cent.

FOUND Carbonic Acid as expired per minute.

Gramme.	Difference.		Per cent.
0·3905 } 0·3881 }	0·0024	=	0·61
0·4581 } 0·4571 }	0·0010	=	0·22
0·4228 } 0·4203 }	0·0015	=	0·35
0·5108 } 0·5087 }	0·0021	=	0·41
0·4403 } 0·4393 }	0·0019	=	0·25
0·4625 } 0·4652 }	0·0027	=	0·58
0·4015 } 0·4007 }	0·0008	=	0·20
0·3630 } 0·3641 }	0·0011	=	0·30
0·4263 } 0·4243 }	0·0020	=	0·47
0·4348 } 0·4345 }	0·0003	=	0·07
0·4246 } 0·4234 }	0·0012	=	0·28
0·4011 } 0 4006 }	0·0005	=	0·12
0·4033 } 0·4046 }	0·0013	=	0·32
0·3766 } 0·3758 }	0·0008	=	0·21
Means . .	0·0013	=	0·31

The following precautions were taken in these analyses as necessary to ensure absolutely correct results by PETTENKOFER's method :—

1. The distilled water used for diluting the solution of barium hydrate (100 to 200 c.c.), was thoroughly boiled, and kept in glass stoppered Winchester quarts. Before using this water it was carefully tested and rejected if one drop of the dilute alkaline solution (25 c.c. normal barium solution in 100 c.c. aq.) failed to show a reaction in about 30 c.c. of the distilled water coloured with two or three drops of solution of turmeric.

2. The same burette was used in every experiment, and every titration was commenced at 0 of the burette scale, the burette being always refilled.

3. The air drawn into the burette by displacement of the fluid was filtered through a tube containing pumice stone moistened with a saturated solution of potassium hydrate in very dilute glycerine, and connected with the burette by a cork and india-rubber tubing. Thus none of the atmospheric carbonic acid could reach the solution in the burette.

4. During the titration air blown from a bellows over pumice stone, moistened with potassium hydrate in dilute glycerine, was driven through the wide-mouth bottle in which the titration was being made, so that atmospheric carbonic acid never came in

contact with the contents of the flask ; this precaution was found absolutely necessary to insure accurate results.

5. The analyses of the alkaline solution were made the day after the experiment except when a Sunday intervened. I have found it necessary not to delay the analyses of atmospheric air, a precaution perhaps less important when a large proportion of CO_2 is present, as occurs in air expired from the lungs.

6. The standard solution of oxalic acid used in PETTENKOFER'S method usually undergoes a change after about a fortnight, when mould is formed in the fluid. In order to avoid any error from this cause, the solution was prepared very carefully by heating the dry flask in which it was to be made to a sufficient temperature to destroy the bacteria, and allowing it to cool with its opening plugged with cotton wool. The weighed oxalic acid was rapidly transferred to the flask, and the solution made with fresh boiled distilled water. The solution prepared in this way keeps for a much longer time unaltered in strength, than if these precautions are not taken.

There is practically I believe, only one source of error in PETTENKOFER'S method of analysis—from the uncertainty of the acidity of the oxalic acid used, as equal weights of different samples do not always give exactly the same degree of acidity. This source of error can be easily obviated by substituting hydrochloric acid for oxalic acid. The analyses referred to in this paper have all been made with oxalic acid from the same stock kept in a glass stoppered bottle.

In order to make quite certain of the strength of the solution, a standard solution of pure hydrochloric acid was prepared by titrating it with a weighed quantity of anhydrous sodium carbonate. The alkalinity of the barium solution was then determined with the standard oxalic acid, and also with the standard hydrochloric acid, while a known volume of the same barium solution was precipitated with sulphuric acid, and determined by weight as barium sulphate. The results obtained were as follows :—

With oxalic acid 100 c.c. barium solution were found equivalent to	0·2683 grms. CO_2
With hydrochloric acid, 100 c.c.	0·2675 ,,
By weight, 100 c.c.	0·2679 ,,

It was therefore obvious that the oxalic acid used in these analyses was quite pure, and moreover that the barium hydrate was uncontaminated with any other alkali.

It has been long known that a certain proportion of the oxygen of the air inspired is not returned in the expired air as carbonic acid, and REGNAULT and REISET in their admirable experiments* have shown that a portion of the oxygen inhaled is occluded in the body. While experimenting on dogs they found the mean relation between the weight of the oxygen expired and the total weight of oxygen consumed

* 'Annales de Chimie et de Physique,' 1849, vol. 26.

to be 0·744. I have subjected human respiration to experiments of a similar description, and obtained results approximating very much to those arrived at by REGNAULT and REISET, but the inquiry was beset with difficulties, and the figures obtained for occluded air do not agree close enough to justify their being quoted on this occasion. We may so far accept an occlusion of from 1·8 to 2 per cent. of the air inspired; therefore, the volumes of air *expired*, as given in this paper, increased by that proportion, will yield very nearly the corresponding volumes of air inspired. Since, however, the air *expired* has only been taken into account in the present inquiry, the results may safely be accepted as correct *relatively to each other* without introducing any correction.

The calculations these experiments necessitated were simple, though somewhat laborious, until I had completed with the aid of Mr. TOWNSEND a table for reduction of volumes, which was found of the greatest use. As I am not aware of such a table of figures being in existence, and as it may be useful to others, it is included in the present communication.

The horizontal headings are Barometer readings from 740 to 780 mm., and the vertical headings are the temperatures from 10° C. to 25° C. inclusive. The reduction of one litre (1000 c.c.) to 0° C. and 760 mm. is given for every Barometer reading from 740 to 780 mm., and every temperature from 10° C. to 25° C.

The correction for fractions of millimetres is *additive* and obtained by multiplying the fraction by the constant 1·2 c.c., or perhaps more correctly 1·25 c.c. The correction for fractions of degrees Centigrade is *subtractive*, and obtained by multiplying the fraction by the constant 4·3. The table was made with the usual formula,

$$V_0 = \frac{Vt(p-f)}{760\,(1+\alpha t)}.$$

Every second or third column of reductions was calculated from the formula, and the intervening ones were calculated with constants. The figures obtained by the use of constants were tested in a number of cases by calculation from the formula and found to be correct within 0·1 per cent. With the assistance of these tables the calculation of a whole analysis could be made easily within a quarter of an hour, in some cases ten minutes were found sufficient for the purpose.

The carbonic acid in the laboratory air was taken into account, though not determined in direct connection with the present experiments. A number of analyses of this air made on previous occasions showing that the mean CO_2 present could be taken in clear weather at 5 parts in 10,000, and in dull weather at 7 parts in 10,000, the carbonic acid expired from the lungs was in every case corrected according to these data.

TABLE for the reduction to 0° C. and 760 mm. of 1 litre of air saturated with humidity, from 10° to 25° C., and 740 to 780 mm.

Temperature.	Barometer.																				
°	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760
10	927·7	928·9	930·2	931·4	932·6	933·9	935·1	936·4	937·6	938·9	940·4	941·6	942·9	944·2	945·4	946·6	947·9	949·2	950·5	951·8	953·0
11	923·6	924·8	926·1	927·3	928·5	929·8	931·0	932·3	933·5	934·8	936·3	937·5	938·8	940·1	941·3	942·5	943·8	945·1	946 4	947·7	948·9
12	919·5	920·5	921·8	923·0	924·2	925·5	926·7	928·0	929·3	930·5	931·8	933·1	934·3	935·6	936·8	938·0	939·4	940·7	942·0	943·3	944·4
13	915·4	916·7	918·0	919·2	920·4	921·7	922·9	924·2	925·4	926·7	928·0	929·2	930·4	931·7	932 9	934·1	935·5	936·8	938·1	939·4	940·5
14	911·3	912·6	913·9	915·1	916·3	917·6	918·8	920·1	921·3	922·6	923·8	925·0	926·2	927·6	928·8	930·0	931·3	932·6	933·9	935·2	936·3
15	907·1	908·4	909·7	910·9	912·1	913·4	914·6	915·9	917·1	918·4	919·6	920·8	922·0	923·3	924·5	925·7	927·1	928·4	929·7	931·0	932·0
16	902·9	904·2	905·5	906·7	907·9	909·2	910·4	911·7	912·9	914·2	915·4	916·6	917·8	919·1	920·3	921·5	922·8	924·1	925·4	926·7	927·8
17	898·7	900·0	901·3	902·5	903·7	905·0	906·2	907·5	908·7	910·0	911·1	912·3	913·5	914·8	916·0	917·2	918·5	919·8	921·1	922·4	923·5
18	894·5	895·8	897·1	898·3	899·5	900·8	902·0	903·3	904·5	905·8	906·8	908·0	909·2	910·5	911 8	913·0	914·2	915·5	916·8	918·1	919·2
19	890·2	891·5	892·7	893·9	895·1	896·4	897·6	898·9	900·1	901·2	902·5	903·7	904·9	906·2	907·4	908·6	909·9	911·2	912·5	913·8	914·8
20	885·9	887·2	888·4	889·6	890·8	892·1	893·3	894·6	895·8	897·1	898·1	899·3	900·5	901·7	902·9	904·1	905·3	906·5	907·7	908·9	910·4
21	881·8	883·0	884·3	885·5	886·7	888·6	889·2	890·5	891·7	893·0	894·0	895·2	896·4	897·7	898·9	900·1	901·3	902·6	903·9	905·2	906·2
22	877·1	878·3	879·5	880·7	881·9	883·2	884·4	885·7	886·9	888·2	889·0	890·2	891·4	892·9	894·1	895·3	896·6	897·9	899·2	900·5	901·4
23	872·6	873·8	875·0	876·2	897·4	878·7	879·9	881·2	882·4	883·7	884·7	885·9	887·1	888·4	889·6	890·8	892·0	893·3	894·6	895·9	896·9
24	868·1	869·3	870·6	871·8	873·0	874·3	875·5	876·8	878·0	879·3	880·1	881·3	882·5	883·8	885·0	886·2	887 5	888·8	890·1	891·4	892·3
25	863·5	864·7	865·9	867·1	868·3	869·6	870·8	872·1	873·3	874·6	875·7	876·9	878·1	879·3	880·5	881·7	882·9	884·2	885·5	886·8	887·9

Temperature.	Barometer.																				
°	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	
10	954·3	955·6	956·8	958·0	959·3	960·6	961·8	963·1	964·4	965·7	967·0	968·3	969·6	970·8	972·1	973·3	974·6	975·9	977·1	978·4	—
11	950·2	951·5	952·7	953·9	955·2	956·5	957·7	959·0	960·3	961·6	962·8	964·1	965·4	966·6	967·9	969·1	970·4	971·7	972·9	974·2	—
12	945·7	947·0	948·2	949·4	950·7	951·9	953·1	954·4	955·7	957·0	958·2	959·5	960·8	962·0	963·3	964·5	965·8	967·1	968·3	969·6	—
13	941 8	943·1	944·3	945·5	946·8	948·1	949·3	950·6	951·9	953·1	954·3	955·6	956·9	958·1	959·4	960·6	961·9	963·2	964·4	965·7	—
14	937·6	938·9	940·1	941·3	942·6	943·8	945·0	946·3	947·6	948·8	950·1	951·3	952·6	953·8	955·1	956·3	957·5	958·8	960·0	961·3	—
15	933·3	934·6	935·8	937·0	938·2	939·5	940·7	942·0	943·2	944·4	945·8	947·0	948·3	949·6	950·8	952·0	953·2	954·5	955·7	957·0	—
16	929·1	930·4	931·6	932·8	934·0	935·2	936·4	937·7	938·9	940·1	941·4	942·6	943·9	945·2	946·4	947·6	948·8	950·1	951·3	952·6	—
17	924·7	926·0	927·2	928·5	929·7	930·9	932·1	933·4	934·6	935·8	937·1	938·3	939·6	940·9	942·1	943·3	944·5	945·8	947·0	948·3	—
18	920·4	921·7	922·9	924·2	925·4	926·6	927·8	929·1	930·3	931·5	932·7	933·9	935·2	936·5	937 7	938·9	940·1	941·4	942·6	943·9	—
19	916·0	917·2	918·4	919·7	920·9	922·2	923·4	924·7	925·9	927·1	928·3	929·5	930·8	932·0	933·2	934·4	935·6	936·9	938·1	939·4	—
20	911·6	912·8	914·0	915·2	916·5	917·7	918·9	920·2	921·4	922·6	923·8	925·0	926·3	927·5	928·8	930·0	931·2	932·5	933·7	935·0	—
21	907·4	908·6	909·8	911·1	912·3	913·5	914·7	916·0	917·2	918·4	919·6	920·8	922·1	923·3	924·5	925·7	926·9	928·2	929·4	930·7	—
22	902·6	903·8	905·0	906·3	907·5	908·7	909·9	911·2	912·4	913·6	914·8	916·0	917·2	918·4	919·7	920·9	922·1	923·4	924·6	925·9	—
23	898·0	899·2	900·4	901·7	902·9	904·1	905·3	906·6	907·8	909·0	910·2	911·4	912·6	913·8	915·1	916·3	917·5	918·8	920·0	921·3	—
24	893·4	894·6	895·8	897·1	898·3	899·5	900·7	902·0	903·2	904·4	905·6	906·8	908·0	909·2	910·4	911·6	912·8	914·0	915·2	916·5	—
25	888·9	890·1	891·3	892·6	893·8	895·0	896·2	897·4	898·6	899·8	900·9	902·1	903·3	904·5	905·7	906·9	908·1	909·3	910·5	911·7	—

The first series of experiments refers to WILLIAM ALDERWOOD, aged 23, a strong man in excellent health, with a well developed chest measuring 83 centims. in circumference at nipples; he weighs 8st. 1lb. without clothes. Seventy-four complete experiments were made in his case, but as they extended from the winter into the spring, the temperature of the laboratory (heated by hot water pipes) underwent rather great changes during that period; this circumstance was found to exert a decided influence on his respiration, the cold reducing the volumes of air breathed for 1 grm. CO_2 expired; hence it became necessary to divide the 74 experiments into two groups, one group including those made at a laboratory temperature varying from 14° to 17°·3 C., and the other group including those made at a temperature varying from 17°·3 to 21°·7 C.

The first group numbered 25 experiments, and the second 49 experiments. The results are given in the form of tables, the means of which have been made into two charts or series of curves (see Plate 1). Each chart shows three curves, one for the carbonic acid, one for the volumes of air expired, and one for the relation between the volumes and the corresponding weights of carbonic acid.

[In relatively cold weather (14° to 17°·3, see table, p. 19) it is difficult to define the precise hour during which the maximum carbonic acid is expired, as the proportion exhaled is relatively high from 0 to 1 hour, 1 to 2 hours, and 2 to 3 hours after food; the actual maximum is from 2 to 3 hours after food, after which time the fall is marked and continued. In relatively warm weather (17° to 21°·7, see table, p. 21) it is also difficult to assign the period for the maximum expiration of carbonic acid, the highest figure is between 1 and 2 hours after a meal, but the fall does not begin till the fourth hour. It may be said that with this person under experiment, the expiration of carbonic acid begins to lessen somewhat earlier after food in cold weather than in warmer weather; but it would be premature to apply this result in a general way.

The chart for the *comparatively cold weather* (WILLIAM ALDERWOOD under experiment) shows distinctly, from an inspection of the curved line marked CO_2, that the carbonic acid expired is high (with a slight fall from 1 to 2 hours after food) till from 2 to 3 hours after food, after which time the fall is rapid and regular till from 5 to 6 hours after food, when the experiments come to an end. In this same chart the curve for the volumes of air expired in comparatively cold weather (see the dotted line) coincides very closely with the curve for CO_2, from 2 to 3 hours till from 3 to 4 hours, and from 4 to 5 hours till from 5 to 6 hours, after food; then, while the line for CO_2 falls fast and regularly, that for volumes of air expired remains nearly horizontal for an hour (from 3 to 4 hours till from 4 to 5 hours after food); this means that the volumes of air are increasing in proportion to the weight of CO_2 they contain, hence the curve for relations shoots up rapidly; but in the following hour (from 4 to 5 till from 5 to 6) the curves for volume and CO_2 show again a marked tendency to coincide.

In the chart for the *relatively warm weather* (WILLIAM ALDERWOOD under experi-

ment) the curve for CO_2 exhibits a slight rise during the first hour after food, then a slight fall and again a slight rise, the maximum being between 1 and 2 hours after food; but the CO_2 remains high till between 3 and 4 hours after food, while by that time the curve was falling rapidly in colder weather. After a period, from 3 to 4 hours after food, the curve falls at somewhat the same speed as it does in colder weather. In this same chart the curves for the volumes of air and CO_2 expired in comparatively warm weather (see the dotted line) coincide very closely with each other from the time food is taken, till from 3 to 4 hours later; then, while the curve for CO_2 continues its regular fall, that for volumes of air expired diverges, crossing the line for CO_2. The effect on the curve for relations is to make it shoot up all but precisely to the same extent as in the corresponding curve for warmer weather. This circumstance certainly shows that the phenomenon is not accidental, but is actually the rule, at all events in the present case. A similar change of coincidence in the curves for CO_2 and volumes of air expired is observed in the other person who submitted to experiment.—*October* 23, 1889.]

WILLIAM ALDERWOOD under experiment.—Table showing (1st) Weight of Carbonic Acid expired per minute; (2nd) Volume of Air expired per minute reduced to 0° and 760 mm.; (3rd) Relation of Volume of Air expired (reduced) to Weight of CO_2. *Temperature of the Laboratory Air at the time of experiment from 14° to 17°·3 C.*

Weight of Carbonic Acid expired per minute in every hour up to six hours after a meal.

Hours after a meal.					
0 to 1.	1 to 2.	2 to 3.	3 to 4.	4 to 5.	5 to 6.
0·460 0·431 0·483	0·485 0·435 0·410	0·512 0·484 0·414 0·395 0·471 0·482 0·505	0·461 0·445 0·429 0·402 0·423	0·444 0·400 0·405 0·385 0·392	0·397 0·376
Means 0·458	0·443	0·466	0·432	0·405	0·386

Volume of Air (reduced) expired per minute.

Hours after a meal.					
0 to 1.	1 to 2.	2 to 3.	3 to 4.	4 to 5.	5 to 6.
3·946	4·402	4·243	4·033	3·984	3·635
3·782	3·924	4·293	3·886	3·883	3·629
4·166	3·800	3·678	3·734	3·700	
		3·543	3·594	3·682	
		4·209	3·845	3·934	
		4·205			
		4·527			
Means 3·965	4·042	4·100	3·818	3·837	3·632

Relation between Volume of Air expired (reduced) and Weight of Carbonic Acid; i.e., *Volume of Air expired for* 1 *grm.* CO_2.

Hours after a meal.					
0 to 1.	1 to 2.	2 to 3.	3 to 4.	4 to 5.	5 to 6.
8 58	9·08	8·29	8·75	8·97	9·16
8·78	9·02	8·87	8·73	9·71	9·65
8·63	9·27	8·88	8·70	9·13	
		8·97	8·94	9·56	
		8·94	9·09	10·04	
		8·72			
		8·96			
Means 8·66	9 12	8·80	8·84	9·48	9·40

WILLIAM ALDERWOOD under experiment.—Table showing (1st) Weight of Carbonic Acid expired per minute; (2nd) Volume of Air expired per minute reduced to 0° and 760 mm.; (3rd) Relation of Volume of Air expired (reduced) to Weight of CO_2. *Temperature of the Laboratory Air at the time of experiment from 17°·3 to 21°·7 C.*

Weight of Carbonic Acid expired per minute in every hour up to six hours after a meal.

Hours after a meal.					
0 to 1.	1 to 2.	2 to 3.	3 to 4.	4 to 5.	5 to 6.
0·421	0·458	0·467	0·465	0·397	0·388
0·456	0·469	0·436	0.489	0·385	0·358
0·472	0·456	0·420	0·438	0·387	0·384
0·430	0·448	0·411	0·417	0·386	0·376
0·424	0·438		0·424	0·370	0·380
	0·440		0·469	0·356	0·352
			0·400	0·381	0·384
				0·395	0·365
				0·442	0·390
				0·356	0·371
				0·383	0·344
				0·368	0·360
					0·349
					0·338
					0·378
Means 0·440	0·451	0·433	0·443	0·384	0·368

Volume of Air (reduced) expired per minute.

Hours after a meal.					
0 to 1.	1 to 2.	2 to 3.	3 to 4.	4 to 5.	5 to 6.
3·933	4·020	4·171	4·152	3·803	3·776
4·161	4·340	4·120	4·477	3·673	3·532
4·389	4·354	3·969	4·041	3·722	3·989
4·049	4·263	3·754	3·856	3·782	3·769
4·036	4·169		3·965	3·704	3·681
	4·115		4·269	3·477	3·378
			3·878	3·676	3·684
				3·817	3·486
				4·185	3·879
				3·484	3·796
				3·701	3 582
				3·704	3·434
					3 381
					3·191
					3·701
Means 4·114	4·210	4·003	4·091	3·727	3·617

Relation between Volume of Air expired (reduced) and Weight of Carbonic Acid; i.e., *Volume of Air expired for 1 grm.* CO_2.

Hours after a meal.					
0 to 1.	1 to 2.	2 to 3.	3 to 4.	4 to 5.	5 to 6.
9·34	8·78	8·93	8·94	9·58	9·73
9·12	9·25	9·45	9·16	9·54	9·87
9·29	9·55	9·45	9·23	9·62	10·39
9·45	9·52	9·13	9·25	9.80	10·03
9·51	9·52		9·35	10·01	9·69
	9·35		9·27	9·77	9·60
			9·69	9·65	9·55
				9·66	9·95
				9·47	10·23
				9·78	10·41
				9·66	9·54
				10·07	9·69
					9·44
					9·79
					9·60
Means 9·34	9·33	9·24	9·27	9·72	9·83

Influence of Atmospheric Pressure on Respiration.

[In order to make the influence of atmospheric pressure on respiration perfectly clear to the reader, the experiments have been disposed in the form of two tables. In the first table they are divided into two groups (under the form of means) of an equal number, the first group including the experiments attended with the highest barometer readings, the second including those attended with the lowest readings. In the second table (pp. 23 and 24) each of the groups of experiments considered (under the form of means) in the preceding table, has been divided into two sub-groups of an equal number of experiments, each of the sub-groups for the *extreme* highest and *extreme* lowest pressures only being entered (under the form of means).—*October* 23, 1889.]

It is certainly unexpected to find that local changes of atmospheric pressure have a most positive and marked influence on respiration, the effect being of the same kind as that I had observed previously in my experiments at increasing altitudes. In order to show the action of the variations of local pressures on respiration it was necessary to eliminate as much as possible the influence of food, and with this object in view the experiments made every *two hours* after a meal were grouped together, and the pressures and corresponding relations for each group placed in a tabular form.

TABLE showing that the Fall of the Barometer is attended by a Reduction in the Volume of air Expired (reduced) for 1 grm. CO_2 (temperatures 17°·3 C. to 21°·7 C.), WILLIAM ALDERWOOD under Experiment. The experiments are divided into two groups—those attended with the highest barometer readings and those with the lowest.

0 to 2 Hours.

	mm.		Litres.
1st group.—Mean highest barometer	765·9	Relations (*i.e.*, vol. air expired per 1 grm. CO_2)	9·423
2nd „ Mean lowest barometer	754·1	„	9·228
Difference	11·8	Fall for 11·8 mm. =	0·195

Number of Experiments, 11.

2 to 4 Hours.

	mm.		Litres.
1st group.—Mean highest barometer	767·0	Relations	9·322
2nd „ Mean lowest barometer	747·7	„	9·180
Difference	19·3	Fall for 19·3 mm. =	0·142

Number of Experiments, 11.

4 to 6 Hours.

	mm.		Litres.
1st group.—Mean highest barometer	766·4	Relations	9·838
2nd „ Mean lowest barometer	746·2	„	9·684
Difference	20·2	Fall for 20·2 mm. =	0·154

Number of Experiments, 27.

EXTREMES. (Temperatures, 17°·3 to 21°·7.)

0 to 2 Hours after Food.

The three Highest and three Lowest Pressures and corresponding Relations.

	mm.		Litres.
1st group.—Mean highest barometer	769·5	Relations	9·517
2nd „ Mean lowest barometer	751·5	„	9·080
Difference	18·0	Fall for 18 mm. =	0·437

2 to 4 *Hours after Food.*

The three Highest and three Lowest Pressures and corresponding Relations.

		mm.		Litres.
1st group.—Mean highest barometer .		768·8	Relations	9·270
2nd „ Mean lowest barometer .		741·7	„	9·260
Difference		27·1	Fall for 27·1 mm. =	0·010

4 to 6 *Hours after Food.*

The six Highest and six Lowest Pressures and corresponding Relations.

		mm.		Litres.
1st group.—Mean highest barometer .		771·7	Relations	10·097
2nd „ Mean lowest barometer .		738·0	„	9·665
Difference		33·7	Fall for 33·7 mm. =	0·432

Therefore, from the present enquiry with reference to this person under experiment, and a similar remark applies to the other, the relations are invariably found to be lowered with falling pressures; or, in other words, with a falling atmospheric pressure the volume of air breathed to expire 1 grm. CO_2 is lessened. This is shown very clearly by a consideration of the ultimate results obtained from the present table, these are as follows :—

From the Collective Readings.

	Fall of barometric pressure.	Fall in the volume of air breathed for 1 grm. CO_2.
	mm.	Litres.
0 to 2 hours after food . .	11·9	0·195
2 to 4 hours after food . .	19·3	0·142
4 to 6 hours after food . .	20·2	0·154
Mean	17·1	0·164

Therefore for a mean fall of 17·1 mm. pressure there was a mean reduction of 0·164 litre in the air breathed to expire 1 grm. CO_2, amounting to a reduction of 0·0960 litre in the volume of air breathed for a fall of pressure of 10 mm.

The extreme readings for barometer and relations (extreme halves of each group) gave much greater differences except in one case, to which special reference will be made ; they are as follows :—

	Fall of barometric pressure.	Fall in the volumes of air expired for 1 grm. CO_2.
	mm.	Litres.
0 to 2 hours after food . .	18·0	0·437
2 to 4 hours after food . .	27·1	0·010
4 to 6 hours after food . .	33·7	0·432
Mean	26·3	0·293

Therefore, for a mean fall of 26·3 mm. pressure, there was a mean reduction of 0·293 litre in the air breathed to expire 1 grm. CO_2, amounting to a reduction of 0·111 litre for 10 mm. pressure. The small figure, 0·010, for the fall of relation from 2 to 4 hours after food, shows that the influence of food appears to interfere with the action of atmospheric pressure. It will now be seen that the fall in the volume of air breathed (for 1 grm. CO_2) is very nearly the same, whether the barometer readings (for every two hours) be taken collectively, or whether the extreme readings only be considered. If the barometer readings be taken collectively, a fall of volume of 0·0960 litre is observed for 10 mm. pressure; if the extreme barometric readings only be considered, the fall of volume will amount to 0·111 litre for every 10 mm. pressure.

The experiments made at a comparatively low atmospheric temperature give similar results as to the effect of barometric pressures, they are, however, too few in number to allow of their being submitted to a special consideration.

The experiments for barometer readings and corresponding volumes of air for the expiration of 1 grm. CO_2 for each person under experiment have been disposed under the form of curves. These curves show that there is a general tendency to a fall of relations with a subsidence of barometric pressure, but from 2 to 4 hours after a meal the influence of food appears to overcome to a certain extent the effect of the barometer, the axis of the curve for relations being nearer to a horizontal line.

The second series of experiments refers to C. F. TOWNSEND, aged 23 years, and weighing 8 stone without clothes; no necessity was found to divide them on account of temperatures; they amount to 56 in number as reported in detail in the accompanying Table (pp. 26 and 27). It will be seen that the maximum weight of carbonic acid (0·439 grm.) and maximum volume of air expired (4·488 litres) occur from 1 to 2 hours after a meal; [but the excess of CO_2 and air expired from 1 to 2 hours after a meal over that expired from 0 to 1 and 2 to 3 hours after food, is so small that the period for the maximum effect is very difficult to define. It has been stated in the abstract of this paper ('Proceedings,' vol. 46) as one of the conclusions arrived at, that these researches confirm "the known usual influence of food on the formation of carbonic acid in the body, the maximum expired occurring between two or three hours after a meal . . ." This result must be accepted in a general way only, as the effect of food upon the formation and elimination of CO_2 appears to vary

with the individual. Moreover, according to my experiments, the influence of digestion towards increasing the formation of CO_2 in the body, which shows itself within the first hour after food has been taken, may last during one or two hours, or even longer, and it is very difficult to assign a period for its maximum effect.—January 4, 1890.]

Three experiments were made before breakfast, yielding a mean of 0·343 grm. CO_2 per minute, and 3·157 litres of air expired.

The curves (Plate 2) for volumes and carbonic acid have not such a parallel course as in the case of WILLIAM ALDERWOOD. Throughout a period of two hours after food the curve for relations is nearly horizontal, showing that the volumes of air and weights of carbonic acid closely follow each other during that time. Then the curve shoots up gradually to the end of the chart. While the line for carbonic acid is seen to fall rather rapidly, the volumes of air expired remain nearly the same.

TABLE showing (1st) Weight of Carbonic Acid expired per minute; (2nd) Volume of Air reduced to 0° and 760 mm. expired per minute; (3rd) Relation of Volume of Air expired (reduced) to Weight of CO_2.—C. F. TOWNSEND under experiment.

Weight of Carbonic Acid expired per Minute in every Hour up to 6 Hours after a Meal.

Hours after a Meal.					
0 to 1.	1 to 2.	2 to 3.	3 to 4.	4 to 5.	5 to 6.
0·465	0·506	0·463	0·388	0·414	0·402
0·411	0·442	0·455	0·425	0·435	0·409
0·451	0·383	0·419	0·397	0·401	0·360
0·445	0·440	0·429	0·386	0·425	0·414
0·398	0·470	0·447	0·397	0·403	0·356
0·430	0·401	0·413	0·462	0·373	
0·401	0·428	0·434	0·405		
	0·406	0·439	0·413		
	0·450	0·440	0·350		
	0·450	0·420	0·440		
	0·454	0·454	0·416		
		0·396	0·394		
		0 372			
		0·410			
		0·431			
Means 0·429	0·439	0·428	0·404	0·410	0·388

Volume of Air reduced expired per Minute.

Hours after a Meal.					
0 to 1.	1 to 2.	2 to 3.	3 to 4.	4 to 5.	5 to 6.
5·080	5·305	4·853	3·937	4·725	4·397
4·175	4·570	4·864	4·583	4·626	4·784
4·572	3·926	4·454	4·449	4·204	4·239
4·424	4·441	4·673	3·994	4·515	4·397
4·163	4·861	4·688	3·603	4·224	4·121
4·197	4·185	4·234	5·069	4·083	
4·012	4·275	4·336	4·369		
	4·115	4·496	4·465		
	4·644	4·515	4·167		
	4·592	4·289	4·557		
	4·454	4·427	4·392		
		3·973	4·047		
		3·960			
		4·425			
		4·474			
Means 4·390	4·488	4·444	4·303	4·390	4·388

Relation between Volume of Air expired (reduced) and Weight of Carbonic Acid; i.e., Volume of Air expired for 1 Grm. CO_2.

Hours after a Meal.					
0 to 1.	1 to 2.	2 to 3.	3 to 4.	4 to 5.	5 to 6.
10·92	10·48	10·48	10·15	11·41	10·94
10·14	10·35	10·68	10·65	10·63	11·69
10·13	10·27	10·63	11·20	10·48	11·77
9·94	10·09	10·90	10·38	10·62	10·62
10·45	10·24	10·48	9·56	10·48	11·57
9·76	10·43	10·25	11·18	10·95	
10·00	9·98	9·99	10·79		
	10·13	10·25	10·82		
	10·31	10·26	11·86		
	10·20	10·21	10·37		
	9·79	9·73	10·56		
		10·07	10·27		
		10·65			
		10·80			
		10·39			
Means 10·19	10·22	10·38	10·65	10·76	11·32

TABLE showing that the Fall of the Barometer is attended by a reduction in the Volume of Air expired (reduced) for 1 Grm. CO_2. (C. F. TOWNSEND under Experiment.)

BAROMETER READINGS AND RELATIONS FROM ALL THE EXPERIMENTS DIVIDED INTO TWO GROUPS.

0 *to* 2 *Hours after Food.*

			Litres.
Mean highest barometer	746·5	Relations (*i.e.*, vol. air expired for 1 grm. CO_2)	10·273
Mean lowest barometer	750·4	,,	10·139
Difference	14·1	Fall for 14·1 mm. =	0·134

Number of Experiments, 18.

2 *to* 4 *Hours after Food.*

			Litres.
Mean highest barometer	766·7	Relations	10 533
Mean lowest barometer	753·9	,,	10·412
Difference	12·8	Fall for 12·8 mm. =	0·121

Number of Experiments, 27.

4 *to* 6 *Hours after Food.*

			Litres.
Mean highest barometer	761·2	Relations	11·157
Mean lowest barometer	752·0	,,	10·767
Difference	9·2	Fall for 9·2 mm. =	0·390

Number of Experiments, 11.

EXTREMES.

0 *to* 2 *Hours after Food.*

The Five Highest and Five Lowest Barometer Readings and Corresponding Relations.

			Litres.
Mean highest barometer	768·6	Relations	10·424
Mean lowest barometer	747·9	,,	10·118
Difference	20·7	Fall for 20·7 mm. =	0·306

2 *to* 4 *Hours after Food.*

The Seven Highest and Seven Lowest Barometer Readings and Corresponding Relations.

			Litres.
Mean highest barometer	770·9	Relations	10·503
Mean lowest barometer	750·8	,,	10·301
Difference	20·1	Fall for 20·1 mm. =	0·202

4 to 6 Hours after Food.

The Three Highest and Three Lowest Barometer Readings and Corresponding Relations.

			Litres.
Mean highest barometer	763·4	Relations	11·544
Mean lowest barometer	747·6	„	10·957
Difference	15·8	Fall for 15·8 mm. =	0·587

This Table shows a result corresponding with that obtained from similar experiments on WILLIAM ALDERWOOD. The fall of Barometric readings and corresponding relations taken collectively give the following figures :—

TAKEN COLLECTIVELY.

	Differences of barometric pressure.	Fall in the volumes of air expired for 1 grm. CO_2.
	mm.	Litres.
Fall of from 0 to 2 hours after food . .	14·1	0·134
„ from 2 to 4 hours after food . .	12·8	0·121
„ from 4 to 6 hours after food . .	9·2	0·390
Mean	12·0	0·215

Therefore, for a mean fall of 12 mm. pressure, there was a mean reduction of 0·215 litre of air breathed for 1 grm. CO_2 expired, amounting to a reduction of 0·179 for 10 mm.

The Table for extreme readings gives :—

	Differences of barometric pressure.	Fall in the volumes of air expired for 1 grm. CO_2.
	mm.	litres.
Fall of from 0 to 2 hours after food . . .	20·7	0·306
„ from 2 to 4 hours after food . . .	20·1	0·202
„ from 4 to 6 hours after food . . .	15·8	0·587
Mean	18·9	0·365

Therefore, with the extreme readings, for a mean fall of 18·9 mm. of the barometer, there was a mean fall of 0·365 litre in the air breathed to expire 1 grm. carbonic acid, amounting to a reduction of 0·194 for 10 mm. This is very near to 0·179, the corresponding figure obtained for the barometer readings and relations taken collectively. Consequently, with one person under experiment, the mean reduction

for the experiments taken collectively amounted to 0·0942 litre for a fall of 10 mm.; and with another it amounted to 0·179 litre. It follows that the effect of falling atmospheric pressures varies in degree with different individuals. The curve shows distinctly, in the case of C. F. TOWNSEND, the same influence of a falling barometer on respiration as the curve for W. ALDERWOOD. From 0 to 2 hours after food, and from 4 to 6 hours after food, there is a distinct fall; from 2 to 4 hours after food the fall is still observed though less marked, showing again that food appears to lessen the influence of the atmospheric pressure on respiration.

The results obtained from the present inquiry are as follows:—

1. The phenomenon is confirmed that less air, reduced to 0° C. and 760 mm., is breathed at high than low altitudes, for the formation in the body of a given weight of carbonic acid.

[2. The experiments on W. ALDERWOOD certainly show that a local fall of temperature is attended with a slight reduction in the volumes of air breathed for the formation and expiration of 1 grm. CO_2, a phenomenon similar to that resulting from a fall of atmospheric pressure.—25th February, 1890.]

3. The influence of food, during digestion, on the formation of carbonic acid, commences within the first hour after a meal has been taken, and lasts for two or three hours, the period for the maximum amount varying throughout that time.

4. The influence of food on the *relation* between the volumes of air breathed and the corresponding weights of carbonic acid expired is clearly shown, the volumes following, more or less, the fluctuations in the carbonic acid; but the CO_2 expired has a marked tendency to fall more rapidly than the corresponding volumes of air as time elapses after a meal. The harmony of the tracings appears to recover itself, however, over night, and the lines are again nearly parallel before the first morning meal.

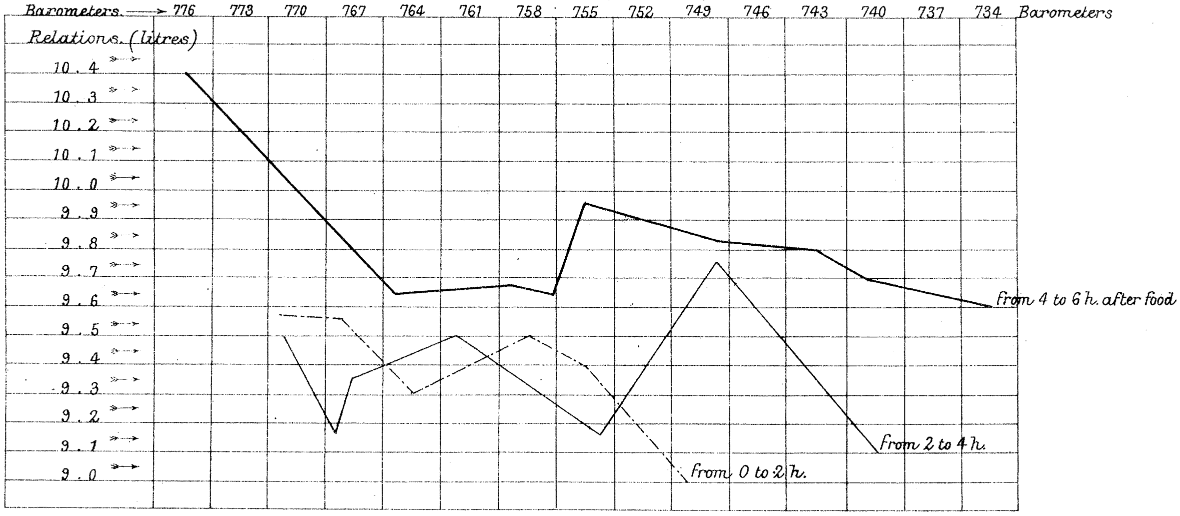
5. The variations of local atmospheric pressures have a marked influence on respiration, less air being taken into the lungs for the formation and emission of a given weight of carbonic acid under *lower* atmospheric pressures than under *higher* pressures; but this influence varies in degree according to different persons. In the present inquiry with two subjects experimented upon; in one case, for a fall of pressure of 10 mm. (0·394 inch), there was a mean reduction of 0·094 litre in the volume of air breathed for 1 grm. CO_2 expired; in the other case, the reduction was greater, and amounted to 0·179 litre.

6. The influence of atmospheric pressures on the volume of air breathed is apparently not the same throughout the whole day, being somewhat less marked from 2 to 4 hours after a meal, when the action of food may be considered at its maximum. Thus, digestion apparently reduces more or less, the effects of any local change of pressure on respiration.

The present investigation shows beyond doubt that different individuals breathe different volumes of air to burn in the body and expire a given weight of carbonic acid. The two persons experimented upon on the present occasion yielded respec-

tively a mean of 9·29 and 10·51 litres, while another expired a mean of 11·30 litres for 1 grm. carbonic acid. No doubt, the less the volume of air inspired for the combustion of a certain weight of carbon the more readily the oxygen taken into the lungs finds its way into the blood, and consequently the more perfect the action of the respiratory organs. In the present case, one of the subjects submitted to experiment was 60 years of age, and he breathed 11·30 litres, against 10·51 litres and 9·29 litres for young men both 23 years of age; although of the same weight, one stronger physically and with a more fully-developed chest breathed (expired) 9·29 litres, against 10·51 for the other, to burn the same weight of carbon in his body.

Chart showing that with a fall of the Barometer, less air has to be breathed to expire 1 gramme. CO_2.
(William Alderwood under experiment)



Charts showing the weight of CO_2 & volumes of Air expired per minute together with their relations.
(W. Alderwood.)

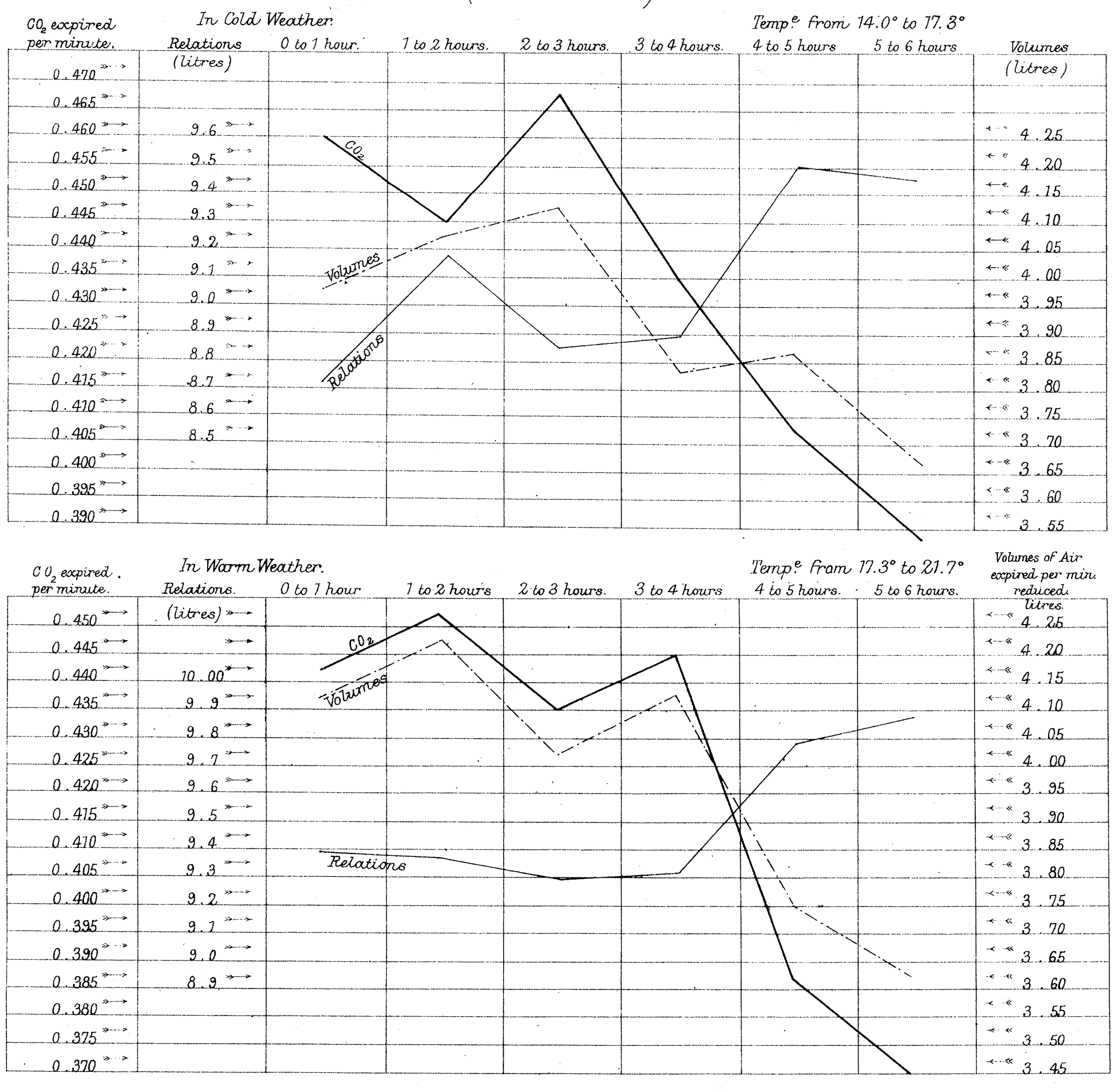
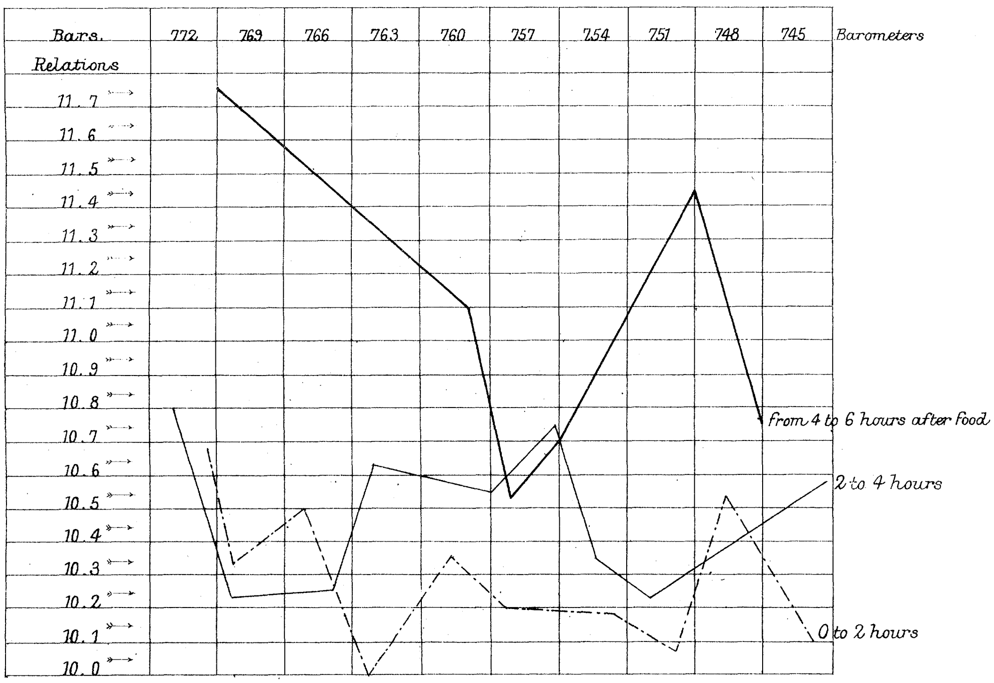
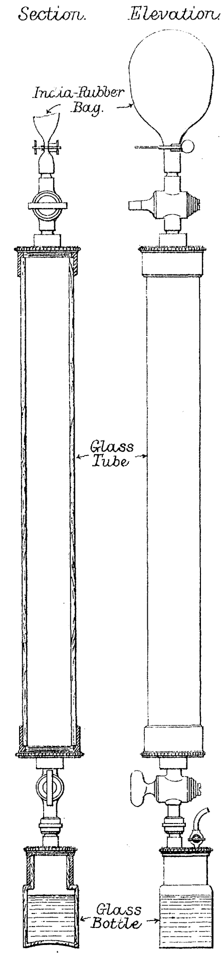


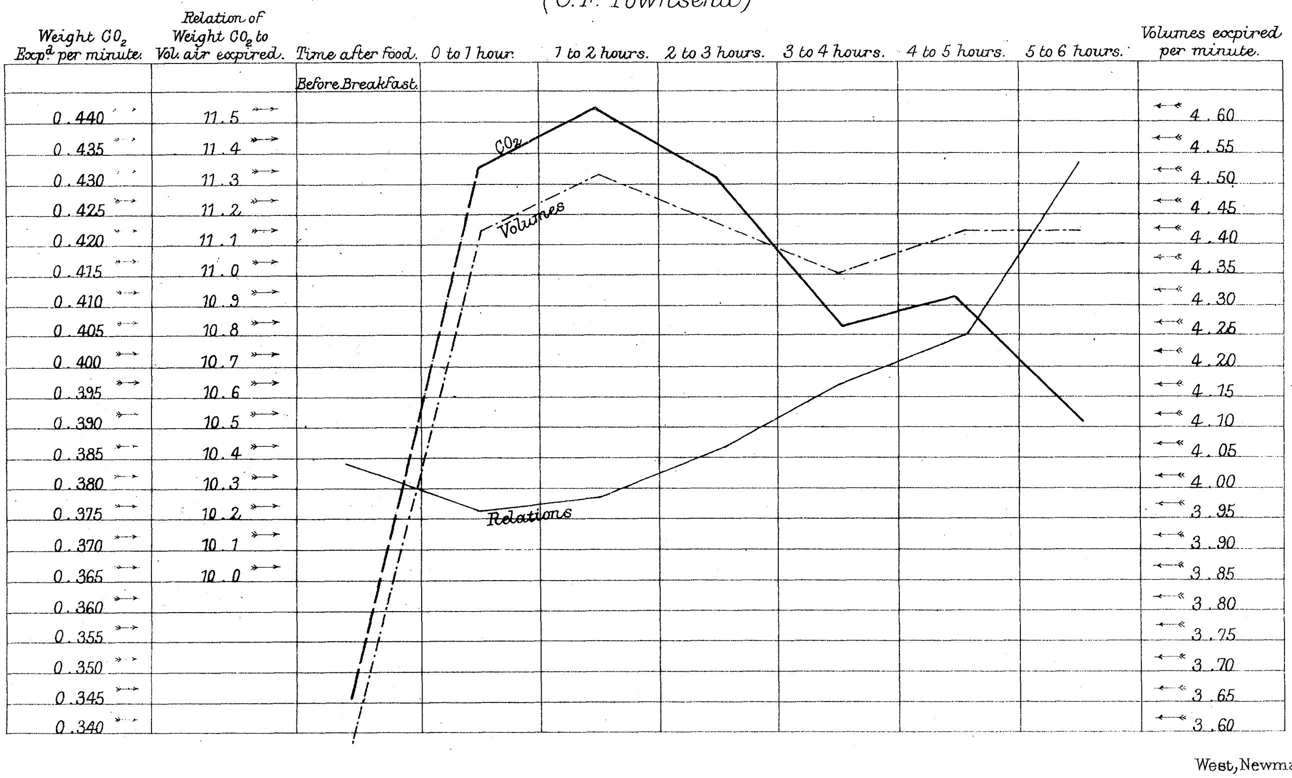
Chart showing that with a fall of the Barometer less Air has to be breathed to expire 1 gramme CO_2
(C. F. Townsend under experiment)





Instrument for the determination of Carbonic acid.

Chart showing the weight of CO_2 & volumes of Air expired per minute together with their relations.
(C. F. Townsend)



West, Newman lith.