XXVI. *Experimental Inquiries into the Chemical and other Phenomena of Respiration, and their Modifications by various Physical agencies.*

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NOTWITHSTANDING the number of valuable observations upon this subject which have been made since the publication of the first memoir of LAVOISIER, there is but little which has been conclusively established. Of the causes inducing this, two have paramount importance, viz. the practice of deducing large from small quantities, in reference to a subject in which the quantities are ever varying, and the absence of any method whereby experiments could be repeated so frequently as to trace the changes actually proceeding during the inquiry. I have named these two because it is to correct them that I have directed my own observations.

During the past year I had the honour to transmit to the Royal Society the results of an extended inquiry into the influence of various agents over the quantity of air inspired, a short abstract of which was published in the 'Proceedings' of the Society. Since that period I have carried the inquiry further, and have determined the influence of those agents over the carbonic acid exhaled, as well as over other phenomena of respiration.

The apparatus employed by previous observers for the determination of the quantity of carbonic acid contained in the expired air, has been one of the following description:—

1st. That adopted by PROUT*, COATHUPE†, VIERORDT‡, and BOEKER§, consisting of a bag or other vessel of known capacity, into which the air was expired during a certain time, and with a noted number of expirations; and a graduated tube, into which a portion of this expired air was passed, and the carbonic acid abstracted by potass, soda, or lime. This was adapted to experiments lasting a few seconds only at a time.

2nd. A box of sufficient capacity to permit a man to be seated in it, and rendered air-tight, except at points which permitted the entrance and exit of air in given directions. The analysis of the expired air was made by the aid of potass. This was SCHARLING'S|| method, and by it he collected the products of the lungs and skin together, during a period not exceeding $1\frac{1}{2}$ hour. It was not practicable to determine the quantity of air

* THOMSON'S Annals of Philosophy, vols. ii. and iv.

† Philosophical Magazine, 1839.

‡ Physiologie des Athmens, &c.

§ Beiträge zur Heilkunde, &c., 1849.

|| Annales de Chimie, vol. viii. p. 478.

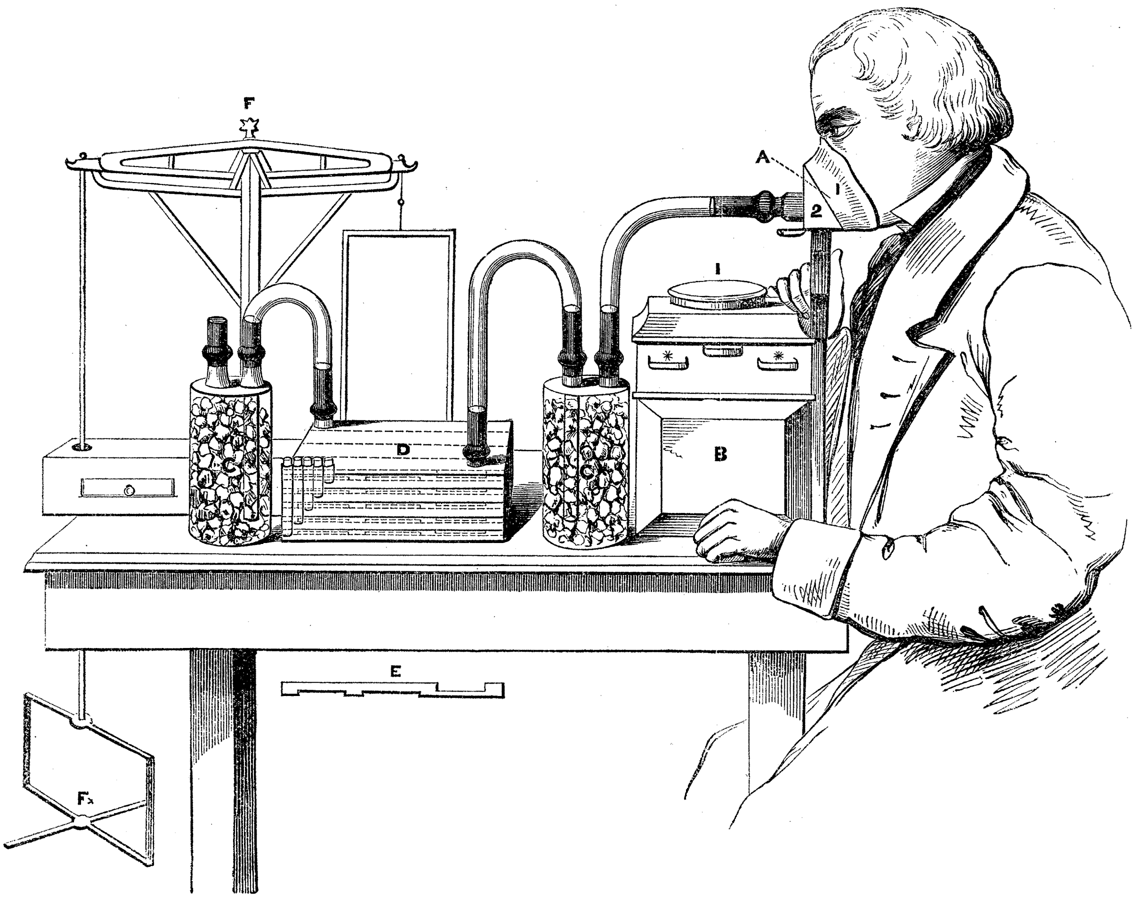
inspired, or to what extent the air was respired more than once; and it was not easy to prove how much carbonic acid remained in the box.

3rd. The method of ANDRAL and GAVARRET*, by which a mask of the capacity of an ordinary expiration was placed over the whole face, and a continuous current of air made to pass through it into an analytical apparatus without respiratory effort.

As the motor power was a vacuum produced in the receiver of the expired air, the duration of each inquiry was limited to about half an hour; and as all the air admitted to the mask and the receiver did not enter the lungs, it was not possible to determine the volume of air inspired.

Hence it was necessary, in order to pursue any serial and long-continued inquiry, to devise a method which had not been adopted by previous observers.

The apparatus which I prepared for the purpose, after a long series of experiments, has already been presented to the Royal Society, and it differs from any heretofore employed, inasmuch as during the act of expiration, and for any length of time, it abstracts the whole carbonic acid exhaled by the lungs. With it was conjoined a small dry gas-meter,



to measure the volume of the inspired air, as described in my former paper. The apparatus and method may be thus briefly described.

* Annales de Chimie, vol. viii. p. 129.

A mask (A) is worn of a capacity only just large enough to receive the nose, lips, and chin, and the apertures of the entrance and exit tubes. The part which sustains the tubes (A 2) and the valves is made of brass, to the free edges of which is soldered sheet-lead of sufficient thickness to remain fixed upon the features when it has been well moulded to them (A 1), and to prevent the entrance of air except through the entrance-tube. Elastic bands are suitably attached to it so as to bind it upon the head, when the hands must be left free for other purposes. The entrance-tube is connected with the spirometer by vulcanized caoutchouc tubing, and during the inspiration of the air the index of the spirometer (B 1) registers the quantity from 1 to 1 million cubic inches. The exit-tube leads to the analytical apparatus, and is connected with it by vulcanized tubing. There are valves suitably arranged to prevent a retrograde current, and so light that they do not offer any important amount of resistance to the current of the expired air.

The analytical apparatus consists of—

1st. A WOULFE's bottle (C), of the capacity of 70 cubic inches, which is filled with pieces of pumice-stone moistened with sulphuric acid. To the bottom of this the current is directed, and in it the vapour is abstracted from the expired air.

2nd. A gutta-percha box (D), consisting of a series of chambers, each $\frac{5}{8}$ths of an inch in depth, and offering a total superficies of 700 inches. The chambers are imperfectly subdivided by partitions (E) into compartments of 2 inches wide, and so arranged that the column of air must traverse the several compartments in each chamber, and each chamber in succession from the bottom to the top of the box. Hence a column of air, 2 inches wide $\times$ $\frac{5}{8}$ths of an inch deep, is directed over an area of 700 inches. This area is occupied by a solution of caustic potash of sp. gr. 1·27, which is introduced into each chamber separately, and which, through fissures in the partitions of the compartments, passes freely over the whole surface of each chamber. By this arrangement all the carbonic acid is abstracted with the rapidity of ordinary expiration; and 30 fluid ounces of the solution was found by experiment to abstract the whole carbonic acid up to 600 grains. (It will be observed that the air is not passed into, but only over caustic potash.)

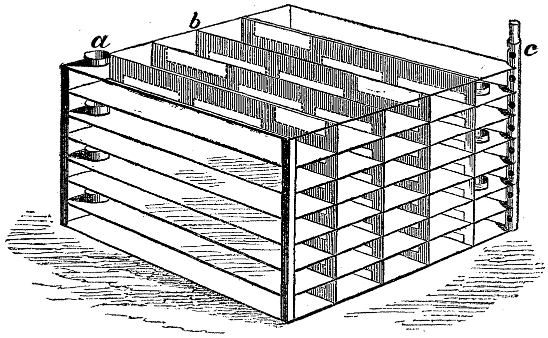
3rd. A second drying apparatus (C), similar to the first one, to abstract the vapour which had been carried off from the solution of potash.

4th. A test of baryta water, over which the current was made finally to pass.

At the conclusion of each inquiry, the increase in weight of the potash-box (D), and the second drying apparatus (C), gave the amount of carbonic acid abstracted; and this was determined by the aid of one of OERTLING's balances (F), constructed to weigh, with great care, to the $\frac{1}{100}$th of a grain, with 7 lbs. in each pan; but it was not employed to indicate less than the $\frac{1}{10}$th of a grain in the large quantity of carbonic acid collected.

The apertures of the tubes throughout the apparatus had an area equal to that of the trachea, so as to offer the least possible resistance to the current of air; a pressure of $\frac{2}{10}$ths of an inch of a column of water sufficed to move the spirometer, and an adverse pressure of about half that amount was offered to expiration. By a series of experiments, I determined the extent to which the drying and carbonic-acid-abstracting apparatus were perfectly efficient; and care was always taken to keep much within those limits. Several

sets of apparatus were at hand, so that by rapidly detaching one and attaching another to the mask (A), a continuous inquiry could be maintained for an indefinite period; and when large quantities of air were required to pass through them (as under the influence



Drawing of a model in the possession of the Royal Society, showing the interior construction of the potash-box. There is a series of chambers communicating by openings which are defended by a flange, as at *a*, and divided by partitions, as at *b*. At *c* there are two sliding tubes, through which the air is passed into the bottom chamber, and through the lateral openings of which the solution of potash is passed into and out of each chamber separately. The openings are closed during the experiment by turning the inner tube half round its axis.

of exertion), a double set was used at the same time. By some of these methods I was enabled to make experiments in sleep, as well as in wakefulness, and with walking or other modes of exertion, as well as at rest; also for one or any limited number of minutes, as well as for hours, and even for the whole day, continuously, except during short intervals for meals. When the experiments were not continuous, they could be repeated every ten minutes. Thus was avoided the fallacy attaching to the different composition of different volumes or currents of the expired air by abstracting the carbonic acid from the whole; and the duration of each inquiry permitted me to escape from the errors of the influence of the mind when directed to the respiration, and of inferring large from very small quantities. In addition to this, I have endeavoured to give a more serial and extended character to the investigations than any hitherto recorded.

The barometric pressure, and the temperature with the wet and dry bulb thermometers, were duly recorded. The time was measured by an astronomical clock.

The objects of the inquiry were, the rate of pulsation and respiration, the quantity of air inspired, and the amount of carbonic acid contained in the expired air. The amount of vapour exhaled was also in a few instances determined; but it was found that the addition of this subject would render the inquiry too burdensome, and incapable of repetition with sufficient frequency.

In the following communication I propose to show—

I. The quantity of carbonic acid evolved, and the changes in respiration, with and without exertion, and with and without food, in the twenty-four hours of the day.

II. The variations from day to day, and from season to season.

III. The influence of walking and the treadwheel.

I. QUANTITY OF CARBONIC ACID EVOLVED, AND CHANGES IN RESPIRATION, WITH AND WITHOUT EXERTION, AND WITH AND WITHOUT FOOD, IN THE TWENTY-FOUR HOURS OF THE DAY.

1. *With ordinary food.*

No inquirer has hitherto collected the whole carbonic acid evolved by the lungs in any considerable part of the day, neither has any one made serial experiments at each of the hours of the day. Numerous observers have made isolated experiments at various periods of the day (some have even experimented during the night); and a few have, on certain days, made inquiries at intervals of about an hour for a large part of the day; and from these experiments, varying in number, duration, and interval, the quantity of carbonic acid exhaled by the lungs in the twenty-four hours has been deduced.

Lavoisier and Seguin*, in their memoir of 1789, state that the medium quantity exhaled by the latter per day was 2 lbs. 5 oz. and 4 gros, but in the memoir of 1790 they reduced it to 1 lb. 1 oz. 7 gros and 4 grs. These quantities represent 10 oz. 4 gros and 5 oz. 7 gros of carbon. They do not give the particulars of their computation.

Coathupe† computes that he expired 5·45 oz. avoirdupois of carbon daily.

Valentin and Brunner‡, from inquiries prosecuted on several persons, give 173 grs. of carbon as the quantity excreted per hour.

Andral and Gavarret§, and Scharling||, from similar inquiries made on a number of persons respectively, state that the quantity of carbon burnt per hour varies from 77·2 grs. to 217·7 grs., and from 80·2 grs. to 154·3 grs.,—quantities equal to 283 grs. and 798 grs., and again to 294 grs. and 566 grs. of carbonic acid per hour.

Vierordt has made a larger number of experiments, and of a more uniform and serial kind than any hitherto published. He found that the medium of five of the highest and five of the lowest experiments gave 7·5 grs. of carbonic acid per minute. The minima were to the maxima as 1 to 2·25.

Barral¶ inferred the quantity of carbon burnt by determining the difference between the quantity contained in the aliment and that found in the excretions. It varied in himself from 8½ oz. to 12 oz. daily at different seasons of the year.

Baron Liebig**, by a similar mode of inquiry upon a large number of Hessian soldiers, found the medium quantity to be 13·9 oz. daily.

I do not think that we are justified in deducing the total quantity of carbon expired in the twenty-four hours from the small quantities determined per minute or per hour as above mentioned, when the authors have declined to do so; for most of the experiments were not intended to embrace all the variations of that period. Andral and Gavarret expressly state that they do not feel warranted in doing so from their experiments. Moreover, no just comparison of the results can be made, since they were obtained under dissimilar and also under unrecorded circumstances; and some of them include the carbon exhaled by the skin also. The following comparison is therefore only to a certain extent true:—

* Mémoires de l'Académie des Sciences. † *Loc. cit.* ‡ Lehrbuch der Physiologie.

§ *Loc. cit.* || *Loc. cit.* ¶ Annales de Chimie, 3 sér. vol. xxv. ** Letters on Chemistry.

Observers.		Subjects of experiment.	Carbon expired in 24 hours. oz.	gros.	
LAVOISIER and SEGUIN . . .		One person.	10 / 5	4 / 7	French.
COATHUPE		One person.	5·45		Avoirdupois.
VALENTIN and BRUNNER . . .		Several.	9·202		Avoirdupois.
ANDRAL and GAVARRET . . .		Several.	4·0068 / 12		Avoirdupois.
SCHARLING	Skin also	Several.	4·4 / 8·464		Avoirdupois.
BARRAL	Skin also . . .	One person.	8·5 / 12		Avoirdupois.
LIEBIG	Skin also	Many persons.	13·9		Avoirdupois.
VIERORDT		One person.	6·78		Avoirdupois.

This Table shows that the estimated quantities hitherto recorded are very diverse, and I now proceed to state the result of my own inquiries.

Four series of inquiries have been instituted to determine these facts. In two (see Tables I. and II.) the experiments were continued during ten minutes, at the commencement of each hour, and also of each half-hour immediately following the meals, whilst in the others (see Tables III. and IV.) the inquiry was continuous, that is, the whole carbonic acid was collected during the whole hours of the working day, with very short intervals for meals. Of the two first, one took place on March 12, 1858, in the Hunterian Museum of the Royal College of Surgeons, by the great courtesy of the President and Council of that learned body, beginning at 7 A.M. and ending at midnight; the other in the house of Mr. MOUL, who, with great devotion to science, gave very efficient aid in this inquiry, continuing from 6½ A.M. until 10 P.M. on May 15.

In the first inquiry the subjects were:—

Myself, æt. 38 years, 6 feet high, 196 lbs. in weight, and a vital capacity of 280 cubic inches.

Mr. MOUL, æt. 48 years, 5 feet 9½ inches high, 175 lbs. weight.

Dr. MURIE, æt. 26 years, 5 feet 7½ inches high, 133 lbs. weight, vital capacity 250 cubic inches.

In the second, myself, Mr. MOUL, and Professor FRANKLAND, F.R.S., æt. 33 years, 5 feet 10½ inches high, and 136 lbs. weight.

The two latter inquiries (or those in which the whole carbonic acid was collected) were prosecuted upon myself alone; one on March 22, in the Hunterian Museum, from 6¼ A.M. until 9½ P.M., and the other in my own house on August 10, from 7½ A.M. until 11½ P.M., with the exception of 1¼ hour in the first, and one hour in the second inquiry for meals at three or four periods of the day. All these inquiries were made in the sitting posture, except during 2½ hours at various times in each of the two last inquiries, when relief was sought in the standing posture, at accurately noted periods. A state of mental and bodily rest was aimed at; but I undertook the weighing, and being alone in the inquiry on August 10, I had also the duty to fill and empty the apparatus; and

hence, without removing from my place, there was a small degree of exertion made. In the two former inquiries exertion was taken in the intervals of the examinations, but we sat down some minutes before each experiment was renewed. It is probable that in Dr. MURIE'S case there was on a few occasions a little excess in the results, owing to the want of close attention to the latter circumstance. On a review of these experiments, I believe that the two former, viz. those in which the experiment was not continuous, may be taken to represent the state of the system at rest, and the two latter in ordinary but not absolute quietude, that is, in the state in which men remain when slightly engaged but not moving the whole body.

The periods above mentioned include nearly 18 hours, viz. from 6 A.M. to 11 P.M., or from 7 A.M. to 12 P.M. all inclusive; and in order to compare them, I have made such addition by computation to each as will include that period; and I regard the results as indicating the true state of the system during the working day. The particulars of the computation are as follows:—

Computation of the Carbonic Acid expired in eighteen hours from the returns obtained in the four inquiries.

March 12. The inquiry embraced the whole period.

May 15. The inquiry was continued through 16½ hours.

			Self.	Mr. Moul.	
		grs.	grs.	grs.	grs.
	16½ hours at	10 per minute (collected) =	9900	at 8·01 =	7950
(6 to 6½ A.M.)	½ hour at	8·85 per minute (computed) =	265·5	at 7·1 =	210·3
(11 to 12)	1 hour at	8·5 per minute (computed) =	510	at 7 =	420
			10675·5		8580·3

In Professor FRANKLAND the average of 15 hours, at 6·66 grs. per minute, was used for the 18 hours=7192·8 grs.

			grs.
March 22.		15 hours' experiment (collected)	9166
	(6 to 6¾ A.M.)	¾ hour's experiment (computed)	353
	(9¾ to 12)	2¼ hours' experiment (computed)	1125
			10644

			grs.
August 10.		16 hours' experiment (collected)	10786
	(6 to 7½ A.M.)	1½ hour experiment (computed)	627
	(11½ to 12)	½ hour experiment (computed)	300
			11713

Food was taken at 8½ A.M., 1½, 5½ and 8½ P.M., in all the experiments. The breakfast consisted of good tea with sugar and milk, bread, butter, bacon or eggs. The dinner, of beefsteak or mutton chop, with bread, potatoes and water. The tea meal, of tea, with sugar and milk, and bread and butter. The supper of boiled eggs, and bread and butter, with water.

The details of the results of these inquiries are given in the following Tables, Nos. I., II., III., and IV.:—

TABLE I.

15·432 grains=1 gramme.
0·06103 cubic inch=1 cubic centimetre.

Experiment made in the Hunterian Museum.

Sitting posture. March 12, 1858.	Temperature.		Barometer.	Duration of each experiment ten minutes.											
				Carbonic acid.			Air.			Pulse.			Respiration.		
	Wet.	Dry.		Self.	Dr. Murie.	Mr. Moul.	Self.	Dr. Murie.	Mr. Moul.	Self.	Dr. Murie.	Mr. Moul.	Self.	Dr. Murie.	Mr. Moul.
h m	°	°	inch.	grs. per min.	grs. per min.	grs. per min.	c. i. per min.	c. i. per min.	c. i. per min.	per minute.	per minute.	per minute.	per minute.	per minute.	per minute.
7 0 A.M.				6·3	6·14	9·5*	453	304	501	84	65	81	15	16	13·9
8 0 A.M.	46·5	50·2		6·25	6·79	8·15	385	444	502	88	65	82	16	14	14·3
8 30 A.M.	Breakfast:—Tea, bread, and bacon.														
9 0 A.M.	47	50·5	29·77	8·7	9·14	8·22	684	526	467	103	77	98	16	19	14
9 30 A.M.	47	50·8	...	7·9	8·06	11·36	464	490	479	92	78	96	16·2	16	14
10 0 A.M.	47	51·2	...	7·44	8·99	8·95	429	507	533	86	77	100	15·2	16·3	14·3
11 0 A.M.	47·9	52·2	...	8·16	8·21	8·83	...	412	499	88	76	91	15·6	15·8	14
12 0 A.M.	48	53	...	8·92	8·2	9·2	644	493	500	79	72	86	15·3	16·4	14·3
1 0 P.M.	49·2	53·9	...	8·95	7·3	7·65	602	529	462	86	72	84	15	14·2	13·8
1 30 P.M.	Dinner:—Mutton, potato, bread, and water.														
2 0 P.M.	49·8	54	...	8·8	8·06	9·08	578	414	512	92	79	89	15·1	14·6	15
3 0 P.M.	49·9	54·1	...	9·1	9·23	8·6	593	501	581	84	70	85	15·4	16	14·9
4 0 P.M.	49·9	54·1	...	9·49	7·05	8·75	605	596	464	88	82	83	15·3	17·2	14·5
5 0 P.M.	49·9	54·1	...	9·57	7·67	6·76	626	...	402	82	76	82	15·1	15·3	15·3
5 30 P.M.	Tea:—Tea, bread, and butter.														
6 0 P.M.	49·9	54·5	...	9·95	9·25	8·1	667	476	464	84	76	82	15·6	15	15
7 0 P.M.	49·9	54·5	...	9·6	8·45	10·1	710	520	540	...	72	87	16·4	16	15·9
8 0 P.M.	49·9	54	...	9·59	7·83	8·3	595	507	463	76	69	83	15·2	13·9	13·8
8 30 P.M.	Supper:—Eggs, milk, bread, and butter.														
9 0 P.M.	49·9	54	...	9·11	7·87	7·75	582	401	448	76	65	79	15·1	14·8	15·7
10 0 P.M.	49·9	54	...	9·55	7·6	8·35	585	437	480	72	66	82	14·1	14·2	14
11 0 P.M.	49·9	54	...	9·38	7·7	8·25	573	405	432	74	60	79	13·4	13	13·1
12 0 P.M.	49·9	54	...	9·52	7·33	7·5	...	398	440	74	58	79	14·2	14·4	14·8

* An excess probably due to previous exertion.

TABLE II.

Experiment made at Mr. Moul's house.

Duration of each experiment ten minutes.

Sitting posture.	Temperature.		Barometer.	Carbonic acid, grains per minute.			Air, cubic inches per minute.			Pulse, per minute.			Respiration, per minute.			Depth of respiration, cubic inches.		
May 15, 1858.	Wet.	Dry.		Self.	Prof. Frankland.	Mr. Moul.	Self.	Prof. Frankland.	Mr. Moul.	Self.	Prof. Frankland.	Mr. Moul.	Self.	Prof. Frankland.	Mr. Moul.	Self.	Prof. Frankland.	Mr. Moul.
h m	°	°	inch.															
6 30 A.M.	57·5	58·5	29·04	8·85	5·15	7·1	491	265	403	65	60	79	12·3	12·3	12·7	39·9	21·5	31·7
7 0 A.M.	59	60	......	8·97	5·43	7·34	464	279	402	64	59	79	12·1	12·5	12·4	38·3	22·3	32·4
8 0 A.M.	60	61	......	8·68	4·58	6·76	470	219	395	63	55	72	11·5	11·2	12·3	40·8	19·7	32·1
8 30 A.M.	Breakfast:—Tea, bacon, eggs, bread, and butter.																	
9 0 A.M.	60·5	61·5	......	10·05	6·01	7·1	551	272	460	74	67	88	12·4	11·8	12·8	44·4	23·1	35·9
9 30 A.M.	60·5	61·5	......	10·41	7·49	8·49	549	375	445	71	63	85	11·6	11·2	12·1	47·3	33·5	36·7
10 5 A.M.	61	62·5	......	10·89	8·32	8·36	560	420	442	74	61	85	12	10·3	12·2	46·8	40·8	36·2
10 35 A.M.	61	62·5	......	11·53	7·47	8·58	579	406	465	76	57	78	11·9	10·9	12·6	48·3	37·2	36·9
11 5 A.M.	62	63	......	11·27	6·23	8·11	478	369	449	71	56	76	11·9	11	12·5	40·1	33·6	35·9
12 0 A.M.	63·5	64·5	......	9·72	6·73	7·16	526	394	406	66	59	74	11·7	12·6	12·2	45*	31·3	33·2
1 0 P.M.	63	64	......	10·01	6·05	7·65	552	366	430	67	55	78	12	11·3	12·6	46	32·4	34·1
1 30 P.M.	Dinner:—Mutton, potato, and water.																	
2 0 P.M.	63·5	65	......	9·4	6·53	7·55	515	359	419	80	63	78	12	11·6	12·6	43·2	31	33·2
2 30 P.M.	63·5	66	......	9·5	6·79	7·58	597	385	391	70	59	78	11·2	11·2	12·8	53·3	32	30·5†
3 0 P.M.	63·5	65	......	9·9	6·45	9·02	517	350	467	73	60	78	11·5	11·3	12·2	45	30·9	38·2
4 0 P.M.	......	......	......	10·82	6·97	8·48	535	401	446	70	59	79	11·1	13	12·6	48·2	28·6	35·4
5 0 P.M.	63	66	......	9·02	6·78	8·05	555	391	420	72	55	78	11·7	12·8	13·1	47·2	30·5	32
5 30 P.M.	Tea:—Tea, bread, and butter.																	
6 10 P.M.	63·5	68	......	9·67	7·0	8·47	590	403	427	73	60	78	11·9	12·6	12·1	49·9	32	35·2
6 35 P.M.	......	......	......	11·49	7·45	8·66	520	423	440	74	58	80	12·1	12·9	11·9	43 ‡	32·8	36·9
7 0 P.M.	......	......	......	11·0	7·75	9·18	533	438	469	73	62	82	11·3	12·9	12·6	47·1§	34	37·2
8 0 P.M.	......	65	......	10·72	7·65	9·35	587	409	456	69	55	78	11	11·7	12	53·3	35	38
9 0 P.M.	......	......	......	9·11	......	8·26	505	......	443	64	......	72	10·8	......	13·3	46·7	......‖	33
10 0 P.M.	......	62	......	8·75	......	7·18	490	......	396	65	......	80	10·4	......	13·8	47·1	......	23·7

* Professor Frankland tested with baryta-water. † Drowsy; full; hot. ‡ Arteries throb; hands swollen. § More sombre. ‖ Dr. Frankland being very tired had left.

Table III.

Experiments made in the Hunterian Museum on myself alone.
Continuous inquiry. Carbonic acid weighed every quarter or half hour.

March 22, 1858.	Temperature. Wet.	Temperature. Dry.	Barometer.	Carbonic acid. per min.	Air. per min.		Pulse.		Rate of respiration.	Posture.
h m	°	°	inch.	grs.	cub. in.		per min.		per min.	
6 45 A.M.	...	...	...	7·93	474	......	77	Little sinking.	...	Sitting.
7 0 A.M.	...	...	30·14	7·53	487	......	75	....	15	„
7 15 A.M.	...	...	...	7·66	449	......	75	....	*15+	„
7 30 A.M.	...	...	...	7·6	429	Little escape.	...	....	15+	„
7 45 A.M.	...	...	...	7·63	446	......	73	....	15+	„
8 0 A.M.	...	...	...	7·6	445	......	76	....	...	„
8 15 A.M.	...	...	...	7·7	481	......	80	....	15	„
8 30 A.M.	Breakfast:—Tea, cold ham, and bread.									
8 45 A.M.	54·5	58·8	...	10·0	579	Walking from	...	....	...	„
9 0 A.M.	...	...	...	11·0	612	breakfast.	89	....	...	„
9 15 A.M.	} ...	...	...	10·2 {	575	......	88	....	15·5	„
9 30 A.M.					582	......	92	....	16	„
9 45 A.M.	54·2	58·5	...	9·9	588	......	90	....	16—	„
10 0 A.M.	...	...	...	9·2	573	......	...	....	17	„
10 15 A.M.	...	...	...	10·2	566	......	78	....	16+	„
10 30 A.M.	...	...	...	10·4	609	......	76	....	17+	„
10 45 A.M.	...	...	...	10·3	597	......	...	....	17+	„
11 0 A.M.	...	...	...	10·5	696	......	82	....	19·5	Standing.
11 15 A.M.	...	...	...	10·7	642	......	...	....	19	„
11 30 A.M.	...	...	...	10·3	687	......	76	....	18	„
11 45 A.M.	...	...	...	10·8	533	......	...	....	...	„
12 3 A.M.	...	...	...	11·4	859	Excited.	...	....	...	Sitting.
12 15 A.M.	...	...	...	10·7	605	......	...	....	...	„
12 33 A.M.	...	...	...	10·9	611	Little excited.	76	....	17·5	„
12 45 A.M.	56·8	60·9	...	10·5	589	......	...	....	17	„
1 0 P.M.	...	...	...	10·3	604	......	77	....	17	„
1 15 P.M.	...	...	...	10·9	556	......	72	Little sinking.	17	„
1 30 P.M.	Dinner:—Mutton, bread, potatoes, and water (enjoyed it).									
1 47 P.M.	..	...	...	9·2	582	Walking from	78	....	16·5	„
2 0 P.M.	58·0	62·0	30·3	9·0	531	dinner.	80	....	16·5+	„
2 15 P.M.	...	...	...	8·9	604	......	...	....	17	„
2 30 P.M.	...	...	...	8·8	568	......	78	....	17	„
2 46 P.M.	...	...	...	9·0	588	......	...	....	...	„
3 0 P.M.	...	...	...	9·8	605	......	...	....	17+	„
3 15 P.M.	...	...	...	9·6	616	......	78	....	17·5	Standing.
3 30 P.M.	...	...	...	9·0	574	......	...	....	17	„
3 45 P.M.	...	...	...	8·3	564	......	90	Little oppressed.	...	„
4 0 P.M.	...	...	...	9·2	580	......	...	....	17	„
4 15 P.M.	...	...	...	8·7	568	......	...	....	...	„
4 30 P.M.	...	...	...	9·9	633	......	...	....	16·5	„
4 46 P.M.	...	...	...	9·5	625	......	...	....	16·5	Sitting.
5 0 P.M.	...	...	...	9·5	576	......	73	....	...	„
5 15 P.M.	...	...	...	8·5	574	......	...	....	16·5	„
5 30 P.M.	Tea:—Tea, bread, and butter.									
5 45 P.M.	...	...	...	10·5	720	Walking from	74	....	18	„
6 0 P.M.	...	...	...	9·7	575	tea.	80	....	19	„
6 15 P.M.	...	...	...	11·2	675	......	...	....	18·5	„
6 30 P.M.	...	...	...	10·1	665	......	80	....	...	„
6 45 P.M.	} Lost time waiting for lamps.									
7 0 P.M.										
7 15 P.M.	...	...	...	8·58	571	......	...	....	...	Sitting.
7 45 P.M.	58·3	63·0	...	8·9	579	......	72	....	...	„
8 15 P.M.	...	...	...	8·5	578	......	...	....	15	„
8 45 P.M.	...	...	...	8·76	590	......	70	....	14·5	„
9 15 P.M.	...	...	...	7·98	535	......	71	....	15	„

* I talked occasionally during the whole inquiry. The signs + and — indicate that the rate of respiration was a little more or a little less than the figures indicate.

TABLE IV.

Experiment made at my house on myself alone.

Continuous inquiry. Carbonic acid weighed only at the hours stated.

August 10, 1858.	Temperature. Wet.	Temperature. Dry.	Barometer.	Carbonic acid, grs. per minute.	Carbonic acid, grs. per minute in each hour.	Air. cubic inches.	Pulse, per minute.	Remarks.	Posture.
h m	°	°	inch.						
7 30 A.M.	......	67·5	29·65	6·96	6·96	475	75	Rain	Sitting.
8 30 A.M.	Breakfast:—Coffee, eggs, bread, and butter (not good one); hurried.								
8 45 A.M.	......	......	......	8·13	9·12	538	79	Perspiring; little excited; very warm	Sitting.
9 30 A.M.	......	69	29·63	12·4	12·4	593	85		
10 30 A.M.	......	70·5	......	10·41	10·42	650	79		
11 30 A.M.	......	71	......	10·96	10·97	578	78	Cooler	Sitting.
12 30 A.M.	......	......	......	10·18	10·91	576	...	......	Sitting.
12 45 A.M.	......	......	......	11·26		584	74	......	Sitting.
1 0 P.M.	......	71·5	29·62	11·04		586	...	Not wanting food	Sitting.
1 30 P.M.	Dinner:—Mutton-pie, potato, and water. Good meal.								
1 46 P.M.	......	......	......	10·13	10·59	501	......	Drowsy	Sitting.
2 30 P.M.	......	73	......	10·1	11·3	557	......	......	Standing from 2·40.
3 5 P.M.	......	......	......	12·48		601	86	Yawning, and oppressed; irritable; bear the experiment badly	Sitting.
3 30 P.M.	......	74·5	......	11·89	11·89	579	......		Legs horizontal from 4·0 to 4·5; standing 4·15 to 4·30.
4 30 P.M.	......	73·3	......	11·62	11·62	547	......	......	Standing ½ hour; sitting 20 minutes; and standing 25 minutes.
5 30 P.M.	Tea:—Tea, bread, and butter.								
5 45 P.M.	......	74·2	......	13·2	13·07	652	......	......	Sitting ½ hour; standing ¼ hour.
6 30 P.M.	......	......	......	11·2	11·21	578	80	......	Sitting ¼ hour; standing ½ hour; sitting ¼ hour.
7 30 P.M.	......	73·8	......	......	12·86	783	......	Lighter and more comfortable	Sitting.
7 46 P.M.	......	......	......	12·74		633	......	Very close; perspiring profusely.	Sitting ½ hour; standing 14 minutes.
8 30 P.M.	Supper:—Milk, oatmeal, and bread.								
8 48 P.M.	......	73·8	......	11·69	11·6	609	75	......	Sitting.
9 30 P.M.	......	......	......	12·3	13·28	579	......	......	Sitting.
9 50 P.M.	......	......	......	13·7		638	......	......	Sitting ½ hour; standing 10 minutes.
10 30 P.M. to 11½	......	74	......	11·32	11·32	567	73	Perspiring	Sitting.

A. *Carbonic Acid evolved.*

The carbonic acid during eighteen hours, or the period constituting the working day, was as follows in oz. avoirdupois (28·332 grms.), in the order of the inquiries as above mentioned.

	March.		May.		Continuous inquiries. March.		Continuous inquiries. August.	
	oz.	grms.	oz.	grms.	oz.	grms.	oz.	grms.
Myself	21·6	(611·97)	24·4	(691·3)	24·328	(689·28)	26·776	(758·44)
Mr. Moul	21·205	(600·78)	19·33	(547·65)				
Dr. Murie	19·582	(554·797)						
Prof. Frankland			16·43	(465·49)				

The average results were,—myself, 24·274 oz. (687·7 grms.) (9·77 grs. per minute), a quantity identical with the results of two out of the four inquiries, and Mr. Moul, 20·267 oz. (574·11 grms.); whilst the total average of the eight sets of inquiries was 21·693 oz. (614·6 grms.), or 8·78 grs. per minute. This contains a total quantity of 5·917 oz. (167·64 grms.) of carbon.

The quantity evolved during the remaining six hours of the day was determined by two inquiries upon myself alone.

On July 15, whilst scarcely awake, at $1\frac{1}{2}$, $2\frac{1}{2}$, and $6\frac{1}{4}$ A.M., I exhaled 5·7, 5·94, and 6·1 grs. per minute, on the average of one-quarter of an hour at each of those hours. On July 16, during light sleep, at 1 and 3 A.M., the quantities were 4·88 grs. and 4·99 grs. per minute on the same average (Table VIII. July 16). As the latter quantities are notably less than the former, and yet the difference in the state of the system was not great, I think it probable that in profound sleep the quantity would be still less, and probably so low as $4\frac{1}{2}$ grs. per minute. The duration of profound sleep is, however, short; for in a series of hourly inquiries into the rate of pulsation and respiration, both in health and disease, published in the Transactions of the Royal Medical and Chirurgical Society for 1856, I showed that the lowest rate of the respiration was from 1 to 3 A.M.; and in applying the above calculation of the influence of profound sleep I limit its occurrence to those two hours. In estimating the state of the respiration in the hour preceding, and also in the hours succeeding, until the hour when my inquiries in the working day commenced, I take the average between the state in profound sleep and at those preceding and succeeding hours. From these data the result is obtained of 1950 grs. of carbonic acid evolved during those six hours; and this, added to the total average of the working day, gives a total for the twenty-four hours in a state of rest of 26·193 oz. of carbonic acid, or 7·144 oz. of carbon.

The same addition being made to the results obtained from each person, the quantities of carbon exhaled in twenty-four hours, in a state of rest, are as follows in ounces avoirdupois:—

Mr. Moul.	Myself.	Professor Frankland.	Dr. Murie.
Æt. 48. 5 feet 9½ inches high. 173 lbs. weight.	Æt. 39. 6 feet high. 196 lbs. weight. Vital capacity 270 cub.in.	Æt. 33. 5 feet 10½ inches high. 136 lbs. weight.	Æt. 26. 5 feet 7½ inches high. 133 lbs. weight. Vital capacity 250 cub.in.
6·735 oz.	7·85 oz.	5·6 oz.	6·54 oz.

In myself the proportion of carbonic acid evolved per hour during the night of six hours, is to the day as 1 to 1·8,—a proportion which differs somewhat from that which SCHARLING found with nine hours' rest.

There yet remains for determination the influence of exertion. There are not on record any experiments in reference to the influence of exactly defined degrees of exertion, except that of raising certain weights through a given space in a given time; but REGNAULT, VIERORDT, and others have ascertained in a general way that exertion increases the respiratory changes. I shall again refer to this subject at a future page.

Whilst walking at two miles per hour during three-quarters of an hour, and carrying the spirometer, weighing 7 lbs., I expired 18·1 grs. of carbonic acid per minute, and 25·83 grs. when walking at three miles per hour. These quantities represent 1·85 and 2·64 times that of quietude in the sitting posture. Hence if three hours were spent in walking at two miles per hour, and one hour at three miles per hour, as is probably the case with the non-laborious class (2½ hours in the standing posture having been introduced into each of the two continuous inquiries above recorded when at rest), the addition to the daily quantity of carbonic acid evolved will be 2463 grs.; and it is probable that thrice that quantity would be applicable to the really laborious class. It is true that these are probabilities and not demonstrations; but if it be desirable to determine the daily amount of carbonic acid evolved by the community, it can only be effected by dividing them into classes, and determining the precise influence of certain agents during their period of action.

These quantities give the following total average results in the twenty-four hours:—

In quietude	26·193	oz. of carbonic acid =	7·144	oz. of carbon
Non-laborious class . .	31·824	oz. of carbonic acid =	8·68	oz. of carbon
Laborious class . . .	43	oz. of carbonic acid =	11·7	oz. of carbon,

or a general average of 33·67 oz. of carbonic acid and 9·18 oz. of carbon.

As some of the elements in this calculation apply to myself alone, viz. those in reference to sleep and exertion, it may be of interest to determine my average apart from that of those who were conjoined with me in some parts of the inquiry. Thus,

In quietude	28·8	oz. of carbonic acid =	7·85	oz. of carbon
As a member of the non-laborious class	33·43	oz. of carbonic acid =	9·11	oz. of carbon
As a member of the laborious class .	45·7	oz. of carbonic acid =	12·19	oz. of carbon,

or a total average of 35·97 oz. of carbonic acid, and 9·72 oz. of carbon in the twenty-four hours.

I do not know how to compare these results with those given by previous observers,

since the degree of exertion and other circumstances are not recorded by the latter, and hence it is impossible to appreciate the state of the system to which they refer.

It is noticeable how great is the difference amongst men in the amount of carbon which they expire—a fact which has been observed by all inquirers. Thus Professor FRANKLAND and myself differed as 2 to 3, and yet we were nearly of the same age and height, but differed greatly in weight and robustness of constitution. Each person also differs much at various periods—a circumstance noticed by BARRAL. Mr. MOUL varied as 10 to 11, and I at least as 11 to 12. Hence it is safer to adopt comparative rather than absolute quantities in determining the quantity of carbonic acid exhaled per day by any individual. Thus if the amount of carbonic acid exhaled in a state of quietude in the day-time be determined by observations made at various periods of the day in relation to the meal hours, the amount exhaled during six hours of the night may be determined by allowing the amount of $3\frac{1}{4}$ hours of the day; and in reference to exercise, by allowing $1\frac{4}{5}$ hour rest for one hour of walking at two miles per hour, and $2\frac{3}{5}$ hours of rest for one hour of walking at three miles per hour.

B. *Quantity of Air inspired.*

In the four series of inquiries now recorded, the quantity of air inspired in cubic inches during the working day was per minute as follows:—

			Continuous inquiries.	
	March. cub. in.	May. cub. in.	March. cub. in.	August. cub. in.
Myself	575	531·5	582·1	583
Mr. Moul	483·1	431·7		
Dr. Murie	464·5			
Professor Frankland		364·4		

The average quantity inspired by myself was 567·7 cubic inches, and by Mr. MOUL 457·4 cubic inches, whilst the average of all the observations was 502 cubic inches per minute.

In order to determine the proportion which the quantity of air inspired bears to the carbonic acid collected (for as I have not measured the expired air I cannot take that as a point of comparison), I insert the following statement of the amount of carbonic acid per minute which was actually collected, with the quantities of air which have just been given. It is as follows:—

					Continuous inquiries.				
	March.		May.		March.		August.		Average.
	Carb. acid. grs.	Air. cub. in.	Carb. acid. grs.	Air. cub. in.	Carb. acid. grs.	Air. cub. in.	Carb. acid. grs.	Air. cub. in.	Carb. acid. grs.
Myself	8·75	575	10	531·5	9·5	582·1	10·9	583	9·79
Mr. Moul	8·6	483·1	8·06	431·7					
Dr. Murie	7·93	464·5							
Professor Frankland			6·66	364·4					

Hence the average of the whole was 8·8 grs. per minute, and the proportion was, in myself, Mr. MOUL, Dr. MURIE and Professor FRANKLAND in order, 1 gr. of carbonic acid to 58 cubic inches, 54·8 cubic inches, 58·5 cubic inches, and 54·7 cubic inches of inspired air, whilst on the whole it was 1 gr. to 56·3 cubic inches. This is a lower proportion than occurs in fasting (the normal state of the system), and much lower than with exertion, in which it increases as the exertion increases. Thus in walking at two miles per hour it was 1 to 44·1 cubic inches, and at three miles per hour 1 to 39·7 cubic inches.

In the above experiments the average temperature with the dry-bulb thermometer was 58°·18, 63°·4, 60°·6, and 72°·2, yielding a total average of 63°·5. The barometric pressure was on the average 29·72, 29·04, 30·13, and 29·63, or a total average of 29·63 inches.

C. *Rate of Respiration.*

This was as follows on the average per minute in each of the three first series of experiments. It was not recorded in the last one.

	March.	May.	Continuous inquiry. March.
Myself	15·2	11·63	16·7
Mr. Moul	14·45	12·6	
Dr. Murie	15·4		
Professor Frankland		11·8	

The total average in myself was 14·54, and in Mr. MOUL 13·5; whilst that of the whole series was 13·87 per minute.

D. *Depth of Inspiration.*

The average depth of inspiration was in myself, 39·5 cubic inches; Mr. MOUL, 33·8 cubic inches; Dr. MURIE, 30 cubic inches; and Professor FRANKLAND, 30·9 cubic inches; giving a total average of 33·6 cubic inches.

E. *Rate of Pulsation.*

In the four series of inquiries the rate of pulsation was per minute—

	March.	May.	March.	August.
Myself	83·7	69·6	78·5	78·4
Mr. Moul	85·7	74		
Dr. Murie	71·3			
Professor Frankland		59·1		

giving total averages in each of 76·5, 79·8, 71·3, and 59·1, and on the whole 71·7 per minute.

The factor of the respirations required to render the numbers of respirations and pulsations equal, was in Mr. MOUL, 5·72; myself, 5·25; Professor FRANKLAND, 5; and Dr. MURIE, 4·63; variations which are very noticeable and follow the order of age. The total average was 5·15.

I have sought to discover a proportion between the pulsations and respirations together and separately on the one hand, and the quantity of air inspired, or the carbonic acid exhaled, on the other; but by no combinations have I been able to discover it. LAVOISIER affirmed that the volume of oxygen consumed was "en raison directe du produit des inspirations par les pulsations." I find that half of the product of the respirations and pulsations will very nearly represent the number of cubic inches of air inspired by myself and Professor FRANKLAND, and in the whole results combined, but it is excessive when applied to Dr. MURIE and Mr. MOUL.

The difference amongst men which has been already noticed in respect to the carbonic acid, is equally observable in all other subjects of inquiry. Thus Professor FRANKLAND and myself differed in the quantity of air inspired as 3 to 5, and in pulsation as 6 to 7. Dr. MURIE exhibited the highest proportion of respirations to pulsations, and Mr. MOUL the least; the former being the youngest, and the latter the oldest subject of the inquiry.

2. *Without food.*

There have been numerous experiments of long duration made on animals whilst fasting, all of which have proved that in the absence of food the quantity of carbonic acid is reduced. No similar experiments are upon record in reference to Man; but LAVOISIER, SCHARLING, VIERORDT, VALENTIN and others, have shown that when the interval between meals is prolonged the same result is obtained.

On July 6 I fasted from 9½ A.M., after a rather small breakfast (12½ hours having elapsed since the previous meal), until midday of July 7, and made an inquiry into the state of the respiration during five minutes at the commencement of each hour, from 1 to 11 P.M. on the 6th, and from 7 to 12 A.M. on the 7th. After having fasted twenty-five hours, I wished to ascertain if starch would produce more respiratory changes when the system was empty of food than under ordinary circumstances, and I took 500 grs. of arrowroot boiled with 10 oz. of water; and having found that the secretions were very alkaline, I took 6 drachms of table vinegar in water in an hour after having taken the starch. The details of this experiment are recorded in Table V. [See opposite page.]

The total quantity of carbonic acid evolved gave an average of exactly 7 grs. per minute. If to this quantity, computed for the eighteen hours of the working day, be added that previously assigned to the six hours of the night, the total quantity of carbonic acid evolved in the twenty-four hours will be 21·73702, containing 5·923 oz. of carbon. The total average of the twenty-four hours was thus 6·61 grs. per minute, and the deficiency from the quantity evolved with food, from the data already given, was 25 per cent., or one-fourth of the larger quantity. The quantity of carbon thus evolved daily in the absence of food is very nearly equal to that contained in 20 oz. of bread, or 7½ oz. of fat.

The quantity of air inspired during the working day, was on the average 367·5 cubic inches per minute. The rate of respiration 10·86, and of pulsation 65·6 per minute. The diminution, when compared with the experiment with food in May, was in the

TABLE V.

Effect of a long fast.

Experiment made at my house upon myself.

Sitting posture.	Temp.		Barom.	Duration of each inquiry five minutes.						
July 1858.	Wet.	Dry.		Carbonic acid.	Air inspired.	Pulse.	Rate of respiration.	Vapour exhaled.	Depth of respiration.	
h m	°	°	inch.	grs. per min.	c.i. per min.	per minute.	per minute.	grs. per min.	cub. inch.	
July 6, 9 30 A.M.	Breakfast:—Coffee, bread, butter, and pickled salmon.									
1 0 P.M.	61·4	63	29·25	7·46	396	71 good	12	2·26	33	
2 0 P.M.	62	63·6	29·25	6·9	369	68 feeble	11·6	2·26	31·8	
3 0 P.M.	62·3	63·8	29·22	7·44	368	......	11·1	1·98	33	
4 0 P.M	61·6	63·6	29·22	7·12	360	67	11	2	32·7	
5 0 P.M.	62	64·3	29·21	7·04	399	62 very soft	11·4	2·06	33·2	
6 0 P.M.	61·8	63·8	29·21	7·0	364	......	11·6	2·08	31·3	
7 0 P.M.	62·2	64	29·21	7·0	375	63 soft	11·4	2·1	32·9	
8 0 P.M.	61·8	63·8	29·21	6·66	359	60 very soft	10·7	1·8	33·5	
9 0 P.M.	62·2	63	29·21	7·04	360	58 very soft	10·7	1·74	33·6	Yawning; much less craving.
10 0 P.M.	...	...	...	7·06	359	58 very soft	10	1·8	33·6	
11 0 P.M.	61	63	29·22	6·52	341	58 very soft	10·3	...	33	
July 7, 7 0 A.M.	60·5	62	29·32	7·02	369	71	10·4	2·02	34·1	Faintness.
8 0 A.M.	61·2	62·3	...	6·58	357	......	10·6	2	33·6	Faintness; sickly; head throbbing.
9 0 A.M.	61·3	63·5	29·32	7·22	369	66 very soft	10·4	2·2	35·4	
10 0 A.M.	61·3	63	29·32	6·68	373	66	10·2	1·94	36·5	
10 21 A.M.	Arrowroot 500 grs., 10 oz. water.									
10 25 A.M.	...	...	...	6·98	384	75 sharper	10·8	2·06	35·5	
10 43 A.M.	...	...	...	7·22	356	73 feebler	10·6	2·2	33·6	
11 0 A.M.	...	...	...	7·22	348	64	10·4	2	33·4	
11 15 A.M.	...	...	...	7·1	370	67 soft	10·3	...	35·8	
11 19 A.M.	Vinegar 6 drachms, 3 oz. water.									
11 22 A.M.	...	...	...	7·6	376	69 sharper	10·4	...	36·1	
11 38 A.M.	...	...	...	7·08	384	73	10·6	...	36·2	Headache; sickly.
11 50 A.M.	...	...	...	7·52	382	71	10·4	...	36·7	

quantity of air 30 per cent., in the rate of respiration about ·7 per cent., and of pulsation about 6 per cent. Hence the rate of the functions was far less variable than the amount of vital action.

At 11 P.M., or $13\frac{1}{2}$ hours after the last meal, I had felt nothing unpleasant. There was a feeling of great tameness, and the pulse was wavy or jerking and very soft. The respiration was feeble. On going to bed I was very cold, and notwithstanding the addition of blankets, it was some hours before my feet became warm. I slept very fairly, and in the morning, at 7 o'clock, the chief feature was still tameness or inaction. There was, however, headache, accompanied by pulsation, and it was increased on lying down. There was also a disagreeable taste in the mouth and sinking at the stomach and bowels. At 9 A.M., the usual hour for breakfast, there was still greatly lessened nervous, mental, and muscular power, a sickly and fainting feeling at intervals, and throbbing in the head constantly; causing with the nausea a most unpleasant but not constant headache. The pulse was still remarkably soft, feeble, and wavy. There was no marked thirst or craving for food. At 10 A.M. the urine was high coloured, alkaline, with a specific gravity of 1·018. The saliva was very alkaline.

The starch and water filled the pulse temporarily, but rather increased than relieved the depressed state of the system. The acid gave almost instantaneous relief to the headache, but the benefit was only temporary, and it did not diminish materially the alkalinity of the saliva. At a little before the experiment ended I was very low and ill. A cup of tea gave no relief, but bread and butter was of some service. At 12^h 10^m I began to eat a good dinner, and took a glass of wine; and so soon as I had fairly began to eat the symptoms abated, and at the end of the meal I was quite well and went about my duties. It is important to remark that nothing but nutriment was of any avail. I had no longing for acids, or for anything in particular, except perhaps potatoes.

Vapour exhaled.—In this inquiry I also determined the quantity of vapour exhaled by the lungs; and although the subject has not been referred to in this paper, the uniform state of the system during fasting afforded so good an opportunity to determine it, that I think it right to insert it.

On the average of the whole inquiry, I exhaled 2·02 grs. of watery vapour per minute during the working day, making a total of 5 oz. avoirdupois in that period. On various other occasions with food I found that the quantity exhaled was from 3 grs. to 3·4 grs. per minute, and hence the diminution during the fast was 37 per cent. The quantity of vapour to each 100 cubic inches of expired air was ·548 gr., and hence assuming that the expired air had a temperature of about 98°, it was but little more than half saturated.

II. VARIATIONS FROM DAY TO DAY, AND FROM SEASON TO SEASON.

α. During the Working day.

1. *With ordinary food.*

Variations in the quantity of carbonic acid exhaled at different parts of the day have been affirmed to occur by SEGUIN, PROUT, ALLEN and PEPYS*, VIERORDT and other

* Philosophical Magazine, 1808, p. 242; Philosophical Transactions, 1809, p. 405.

observers, and they have been ascribed to food, exertion, and sleep. Some of these observers, as Prout and Coathupe, determined only the per-centage in the expired air; an inquiry of no value in determining the total amount of carbonic acid exhaled. Lavoisier states that the quantity differs every moment, and with every person, but each person has a law for himself. Scharling states that the proportion of the night to the day varied from as 1 to 1·225 to as 1 to 1·42, whilst Marchand regarded the difference as inconsiderable and due simply to quietude. In my experiments the variations during the day were extremely great, so much so that the maximum and minimum quantities of carbonic acid usually differed to the extent of more than half the latter. They were as follows in grains per minute in the four sets of inquiries:—

	Min.		Max.		Min.		Max.		Min.		Max.
Myself	6·25	and	9·59	Mr. Moul	6·76	and	11·56	Dr. Murie	6·14	and	9·25
	8·68	and	11·53		6·76	and	9·35	Professor Frankland	4·58	and	8·32
Continuous inquiries.	7·81	and	11								
	6·96	and	13·3								

the total being 6·74 and 10·43 grs. per minute.

These variations were due to food, and were of such a nature that an increase began directly after a meal and progressed to a maximum, after which they declined gradually to a minimum until the following meal.

Generally the maximum quantity was observed in from one to two hours after a meal, and after each meal, but after the breakfast and tea meals it was the greatest, and both were nearly the same. The minima were observed before a meal, and hence there were five in each day, viz. before breakfast, dinner, tea, and supper, and some time after supper; and it is very noticeable that they were nearly the same at each of those periods. Hence there is in a state of quietude in each day a minimum line below which the system does not pass, and also a maximum which it does not exceed, the difference between the two being due to the temporary influence of food. In several of the inquiries, however, as for example in that of Professor Frankland, in my first and in Mr. Moul's second experiment, there was not in the afternoon the ordinary amount of diminution in the quantity of carbonic acid exhaled; and as this was exceptional, and we dined before our usual dinner hour, it was probably owing to food having been supplied before the action upon the respiration of the previous quantity had ceased (Plate XXXIII. fig. 1, March 12). There can be no doubt that, with a suitable interval between meals, there are striking alternate elevations and depressions in the line representing the quantity of carbonic acid excreted.

A reference to the above maximum and minimum quantities, and to the variations hour by hour as shown in the Tables I. II. III. and IV., with the want of uniformity in any of these quantities, proves that any attempt to determine the whole carbonic acid evolved in a day from isolated or irregular observations must be futile. They,

however, show that observations taken at the period of the day when the quantity of carbonic acid evolved is at the lowest point, viz. four to five hours after a meal, will be nearly uniform, and that the excess due to food may be approximately arrived at by taking observations at 1½ to 2½ hours after the meal, and deducing the average from those quantities.

2. *Without food.*

The variations in the respiratory phenomena in the working day were so small, that at 2, 4, 5, 6, 7, 9 and 10 o'clock P.M., on July 6, all the quantities were almost identical with those at 7 on the following morning. The maximum and minimum quantities of carbonic acid were 6·52 grs. and 7·44 grs.; of air inspired, 399 cubic inches and 341 cubic inches; rate of respiration 12 and 10·2, and rate of pulsation 71 and 58 per minute —quantities which contrast in a remarkable manner with those previously shown to occur with food. In Plate XXXIII. fig. 1, the variations with and without food are contrasted.

Hence there is great uniformity in the respiratory phenomena during a long fast; but it was noticeable that on the occasions when the carbonic acid would have increased with food, there was a slight decrease without food—a fact corresponding with that which I recorded in the Transactions of the Royal Medical and Chirurgical Society for 1856, in the rate of the functions on five persons of different sexes and ages. A low and uniform state of system is therefore the characteristic condition in a prolonged fast; and it is very like that which occurs with food at the end of the interval between the meals. It has also been shown that in a fast of this duration the quantity of carbonic acid does not progressively diminish, but is the same at the end of twenty-seven hours as it was at the end of 4½ hours.

There is therefore a state of the system which is nearly uniform under all the circumstances of the day, when the body is uninfluenced by exertion or the primary processes of digestion, and which may be called the basal or normal state. From this but little can be taken away; and the additions must be due to exertion or the temporary influence of compound aliments. This I shall subsequently show to be a fact of much interest and importance, since it will be proved that certain substances which, as food, must contain nutriment, do not increase the products of respiration over this basal line; whilst others, including all compound aliments, do produce an increase.

The great uniformity in the state of the system during fasting renders that period particularly fitted for the determination of the numerical relations between the carbonic acid, air inspired, and rate of pulsation and respiration, and also as a basis with which to compare the influence of food and other agents. The law before mentioned in reference to myself was well exemplified in this experiment; for the cubic inches of air inspired are very nearly represented by the half of the product of the pulsations and the respirations. There was 1 gr. of carbonic acid to 52·5 cubic inches of air; which if we consider it as a normal, the proportion with food is less and with exertion is greater.

This experiment also confirms REGNAULT'S observation, that the composition of the expired air is uniform during fasting.

In reference to the variations of the day in the quantity of vapour exhaled, the highest amount (2·26 grs. per minute) was obtained in the two first hours of the inquiry, or those nearest to the last meal, and the lowest amount (1·74 gr.) was obtained after 8 P.M. On the following morning the quantity was increased to 2·2 grs. per minute, and it did not exceed that after I had taken the arrowroot and water.

I do not find any observations on record with which I can compare these results.

There yet remain for examination two other sources of variation in the respiratory phenomena, viz. those occurring at short intervals from day to day, and those extending over a lengthened period of months and associated with season. I shall now describe them.

The experiments connected with both heads of the inquiry were made in the investigation of the influence of food, and under precisely the same external circumstances as to period of the day, food, exertion and excitement; for they were all made between 7 and 8 A.M., before breakfast, in the sitting posture, and in the absence of all exertion and mental excitement. They were commenced on March 30, and were continued with regularity by Mr. MOUL and myself until the middle of June, and then by myself alone until the present time.

β. Variations from day to day.

Nearly all observers have found that the absolute quantities recorded on any day did not correspond with those of other days; but as the inquiries were not made under precisely the same external circumstances, it was not possible, with certainty, to assign any cause to which the variation could be attributed. It would not perhaps be unreasonable to presume that, with identity of external circumstances on successive days, the system would not vary in any appreciable degree; but a reference to Plate XXXIV. will show that whilst in not a few instances the quantities obtained were constant, in many others the variation from day to day in the amount of carbonic acid amounted to half a grain, and in a few to even one grain per minute; and that this was not due to any error in the inquiry, may be inferred from the fact that, when a food was under examination which did not vary the respiratory changes, the same numbers were obtained in several successive experiments within from one to two hours. Hence we must search within the system for the explanation, and we shall find reason to believe that the nature of the night's rest, and the amount of nutriment remaining in the system, cause variations in the amount of carbonic acid expired in the early morning, before food has been taken. On many occasions I noted these conditions at the time that I made the experiment. Thus I passed a restless night on April 7, June 1, 16, 18, 23 and 24; had short night's sleep on April 24 and 28; was not well on April 15, 16, May 8, 18, June 14, and

September 14; and in almost every instance there was a fall in the quantity of carbonic acid on the following morning (see Table). I passed a good night and was very well on April 20, 26, 30, May 19, 20, 24, June 4, 21, July 1, September 19, and November 4, and with equal uniformity the carbonic acid was increased (see Table). These may be appreciated by referring to Plate XXXIV.; and it will also be observed that the changes were extremely well marked on May 18, 19, 20, 31, and June 1. With a large supper of meat there was an increase, but with a late supper with tea or coffee there was a decrease. With much food taken during the preceding day, there was on May 31 an increase so large as to look like an error, whilst on the succeeding day, on which there was an unusual amount of exertion and deficiency of food, the decrease was equally great.

Carbonic acid.	
Increase.	Decrease.
gr.	gr.
−0·29	−0·6
+0·1	−1·5
+0·8	−0·3
+0·44	+0·18
+0·6	−0·58
+0·58	+0·22
+0·2	−0·36
−0·2	+0·2
+0·68	−1·32
+0·16	+0·16
	−0·26
	−1·12
	−0·67
	−0·27

The uniformity in these results is too striking to admit of their being merely coincidences; and whilst the general feeling of the system may not admit of very accurate and minute definition, I believe that the following statement may be relied upon, viz. that with much food on the preceding day, with good and long night's rest, and with a feeling of health and good spirits, the quantity of carbonic acid evolved before breakfast is greater, whilst it is lessened by the contrary conditions. The hour of supper and the nature of the food then taken will also vary the quantity. The mode by which tea and coffee act will be explained in a subsequent paper. I have not recorded many observations in reference to the effects of spirituous liquors; but whenever I had taken them at a late hour, it is recorded that the carbonic acid was lessened, but it is also stated that I had passed a restless night. The conditions favourable to the production of a large amount of carbonic acid in the morning are such as have tended to induce profound and continued sleep, whilst in the adverse conditions there has been an unusual nocturnal activity of the respiration. This is agreeable to *à priori* reasoning; but I do not know that it has been hitherto demonstrated, and by it we may explain much of the remarkable differences in the returns from day to day, and many diversities in the relative quantities evolved by myself and Mr. MOUL.

γ. Variations connected with Season.

BARRAL* states that he excreted considerably more carbon in winter than in summer; and a similar observation was made by VIERORDT; but their observations were not made with such regularity and with such identity of external conditions as to eliminate the true effect of season.

Mr. MILNER†, Surgeon to the Wakefield Prison, in a paper recently read before the British Association, found, in an experience of ten years, and from 40,000 weighings, that the prisoners, on the average, gained in weight from March or April to September, and lost weight during the other months of the year.

* Annales de Chimie, 3 sér. vol. xxv. p. 165.

† Sanitary Review, 1858.

The general expression of the results obtained by me is, that the advancing hot season lessened all the vital and mechanical changes of respiration, viz. the quantity of carbonic acid expired and of air inspired, the rate and depth of respiration, the quantity of vapour exhaled, and the cooling of the body. These include lessened muscular and vesicular actions and chemical changes. With the return of the cold season the quantities increased. All the results are delineated in Plate XXXIV., which shows the quantity of air inspired and of carbonic acid expired, with the rate of respiration and pulsation contrasted with the temperature during each month of the year.

The results obtained from myself correspond in all essential particulars with those obtained from Mr. Moul, except that the changes were induced in him more quickly and powerfully. Hence I infer that he was more susceptible to seasonal influences; and this was in conformity with a law which I evolved in former researches at the Hospital for Consumption, and published in the British and Foreign Medical and Chirurgical Review, April 1856, viz. that all who bear heat badly have an excess of all the seasonal effects, for he suffers much from heat, whilst I bear it well. I was thus fortunate in having an example of the two classes of persons. I will first describe my returns, and then those of Mr. Moul.

On the average of the second week in April I inspired 550 cubic inches of air per minute in sixteen inspirations, and expired 8·65 grs. of carbonic acid per minute; but on the average of a whole month, from the middle of July to the middle of August, the quantity of air was reduced to 386·4 cubic inches, of carbonic acid to 7·27 grs., and rate of respiration to 11 per minute. Hence there was a diminution of 30 per cent. in the quantity of air, 32 per cent. in the rate of respiration, and 17 per cent. in the quantity of carbonic acid; so that the proportion of the carbonic acid to the inspired air was greater, although the total amount was lessened. Up to the end of May the quantity of carbonic acid did not fall below 8 grs. per minute, and on many occasions it exceeded 9 grs.; but as June advanced the quantity progressively fell, so that it was often under 8 grs., but never above 8 grs. per minute; and after the 22nd of June, until the middle of August, the quantity was between 7 and 8 grs. Hence the beginning of June was the true period of commencement of seasonal decline in the respiratory changes. The period of the commencement of increase was October, and the increase continued in the succeeding months.

The relation of the carbonic acid expired to the air inspired varied each month as follows, from April to October inclusive:—

April.	May.	June.	July.	August.	Sept.	Oct.
1 gr. to 58 cub. in.	50·7 cub. in.	52 cub. in.	51·5 cub. in.	54·8 cub. in.	56·3 cub. in.	51·4 cub. in.

In the first week of April Mr. Moul inspired 477 cubic inches of air per minute, at a rate of respiration of 16·4 per minute, and with an evolution of 8·28 grs. of carbonic acid per minute; but by the fourth week of that month he had lost more than 20 per cent. of air, 18 per cent. of carbonic acid, and 13 per cent. in the rate of respiration. Thus the proportion of carbonic acid to the air inspired was scarcely changed. After that period the quantities increased from the 8th to the 18th of May; but on the averag

there was a further decline in all the respiratory phenomena, until the termination of his experiments at the middle of June. The extreme loss from season on the weekly averages, up to the middle of June, was 27 per cent. of carbonic acid, 27 per cent. of air, and 28 per cent. in the rate,—a degree of uniformity in the phenomena exceedingly striking.

In Mr. MOUL the greatest and most sudden changes occurred in the early spring. I had but little change in the spring, but there was a great decline in summer, which continued until the autumn; and although Mr. MOUL'S experiments ended before midsummer, the progression of his returns give us the right to infer that at the end of summer his quantities would also have been much reduced. Hence there is a close and significant relation between the activity of the vital changes in Man and plants at those two periods, to which common experience has ever attached great importance, viz. the spring and fall with their variations proceeding in yearly cycles.

Having thus briefly stated the changes which occurred, it is now needful to determine to what elements in "season" they are to be attributed. Of these, Temperature and Atmospheric Pressure are two of the most important, and have been investigated by other observers. I have complete records of the former, and incomplete records of the latter.

A. *Temperature.*—The returns prove that the relation between the quantity of carbonic acid evolved and the temperature of the air is an inverse one, as VIERORDT and others had established; but they also show that there is no absolute relation between a given temperature and the carbonic acid—a circumstance which has not been hitherto demonstrated.

The effect of the first sudden elevation of temperature in April is strikingly corroborative of the former assertion. Thus from March 31 to April 14, the temperature gently and progressively fell from 56°·5 to 47°·5, and then it suddenly rose 6°·5 in one day, and became so high as 63°·6 in ten days, after which it rapidly fell. Until April 14, with declining temperature, my returns show an increasing quantity of carbonic acid of more than 1 gr. per minute, ending in the large quantity of 9½ grs. per minute. On the contrary, Mr. MOUL'S returns show a progressive decrease of more than 1 gr. per minute. The Table and Plate XXXIII. figs. 2 & 3, show the coordinated movement of the lines of temperature and carbonic acid during the period of the sudden increase of the former.

Thus in my returns the carbonic acid suddenly decreased 1·3 gr. per minute, and almost as suddenly increased nearly 1 gr. per minute, the former corresponding with the accession and the latter with the decline of temperature. Mr. MOUL'S decrease was greater, and had its maximum on the day of the maximum temperature, whilst the increase was extremely great and rapid immediately after the temperature began to fall. After this period, to the beginning of June, the curves of temperature and carbonic acid in Mr. MOUL'S returns are opposed with tolerable uniformity; and on the occurrence of the second elevation of temperature at that period, there was again a sudden and temporary diminution of carbonic acid.

The contrast of the *monthly averages* is of great interest. Thus—

Table VI.

Comparison of *Monthly Averages* of Respiratory and Meteorological Phenomena.

1858 and 1859.	Myself.						Mr. Moul.			
	Temp. Dry.	Barom.	Carbonic acid, per min.	Air, per min.	Pulse, per min.	Respirations, per min.	Carbonic acid, per min.	Air, per min.	Pulse, per min.	Respirations, per min.
	°	inch.	grs.	cub. inch.			grs.	cub. inch.		
April ...	54·5	28·84	8·58	498	72·8	14·3	7·18	429	80·3	15·6
May ...	58·1	29·51	8·89	451	68·3	12·4	6·63	384	82·1	12·75
June ...	71·7	29·61	8·19	426	71·1	11·64	6·34	367	79·9	12·6
July ...	65·1	29·48	7·62	393	69·8	11·				
Aug. ...	66·6	29·49	7·15	392	73·3	10·9				
Sept. ...	61·2	29·51	7·13	402	66·6	10·94				
Oct. ...	52·8	29·38	7·67	395	69·8	10·93				
Nov. ...	43·8	29·28	7·86	414	69·1	10·87				
Dec. ...	45·2	29·43	8·27	429	67	11·15				
Jan. ...	43·1	29·64	8·35	447	68·8	11·73	See *Note*, page 708.			
Feb. ...	46·3	29·58	8·2	......	69·2	11·35				
Mar. ...	48·9	29·47	8·25	......	70·9	11·38				

Moreover, the quantity of carbonic acid evolved in different *decades of degrees* of temperature shows that the relation is an inverse one. Thus in the four decades from 40° to 80°, the quantities evolved by Mr. Moul were in the ascending order—7·58 grs., 7·237 grs., 6·45 grs., and 6·37 grs.,—a series continually decreasing; but the rule is not so well exemplified in myself (for a reason to be presently explained), since the quantities were 8·44 grs., 8·527 grs., 7·841 grs., and 8·29 grs. in their order.

The *weekly averages* show that in myself the rule was maintained in fourteen of twenty-four weeks, and in Mr. Moul in eight of eleven weeks.

Hence it must be admitted that there is an inverse relation between *seasonal* temperature and the respiratory changes.

But it is evident—and it is a fact of great interest—that there is no uniform relation between the degrees of temperature and the carbonic acid, such as would be necessary to determine the degree of dependence of the one upon the other. This will be proved in two ways: first, by showing the changes which occurred during the long period of months constituting each season; and secondly, the sudden increase of temperature in April.

Mr. Moul's returns are more uniform than mine, and yet in those the progressive decrease of carbonic acid with increasing decades of temperature is so irregular, as ·343 gr., ·887 gr., and ·08 gr. In mine there was an *increase* in the second and fourth decades. It is also shown in the foregoing Table, that the lowest state of the respiration did not occur with the highest temperature of the season, but after the lapse of two or three months, and the loss of 5° or even 10°, yet with the temperature always exceeding 60°. Further, the following Table shows that the same temperature is attended by the most diverse quantities of carbonic acid; as for example 59°, in which I have returns in five months, the monthly averages are 8·11 grs., 9·13 grs., 7·64 grs., 7·3 grs., and 6·76 grs. in their order; and to take an illustration from Mr. Moul's returns, at the temperature of 52°, the returns of two months are 9·36 grs. and 6·3 grs.; and at 53°, 8·32 grs. and 6·35 grs. These returns, with others, are found in the following Table, which I think is worthy of close attention.

Table VII.

Showing the carbonic acid (in grains per minute) exhaled, on the average of all the observations made at each degree of temperature, in different months, and also the total averages.

Myself.

40°.	41°.	42°.	43°.	44°.	45°.	46°.	47°.	48°.	49°.
April	...	...	...	...	...	...	9·46	8·28	8·91
May	...	...	...	...	...	...	...	...	...
June	...	...	...	...	...	...	...	...	...
July	...	...	...	...	...	...	...	...	...
August	...	...	...	...	...	...	...	...	...
September	...	...	...	...	...	...	...	...	...
October	...	...	...	...	...	...	8·06	...	...
November	8·56	...	...	8·22	...	7·83	...	8·38	...
All	8·56	...	...	8·22	...	7·83	8·76	8·33	8·91
Before July	...	...	...	...	...	...	9·46	8·28	8·91
After June	8·56	...	...	8·22	...	7·83	8·06	8·38	...
Total Average	Before July 8·88			(All 8·44)			After June 8·21		

40°.	50°.	51°.	52°.	53°.	54°.	55°.	56°.	57°.	58°.	59°.
April	9·1	8·2	7·96	8·34	8·14	...	8·55	9·04	8·68	8·11
May	...	...	9·8	9·24	8·4	8·83	8·8	...	8·44	9·13
June	...	...	...	...	...	...	...	...	...	...
July	...	...	...	...	...	...	...	...	...	7·64
August	...	...	...	...	...	...	...	...	...	...
September	...	...	...	...	...	...	...	...	...	7·3
October	...	...	...	...	...	...	7·84	...	7·0	6·76
November	...	8·06								
All	9·1	8·13	8·88	8·79	8·27	8·83	8·39	9·04	8·04	7·79
Before July	9·1	8·2	8·88	8·79	8·27	8·83	8·67	9·04	8·56	8·62
After June	...	8·06	...	...	...	...	7·84	...	7·0	7·23
Total Average	Before July 8·69				(All 8·527)			After June 7·43		

40°.	60°.	61°.	62°.	63°.	64°.	65°.	66°.	67°.	68°.	69°.
April	8·08	...	8·4	8·4						
May	8·36	9·32	9·1	8·66						
June	...	...	...	7·77	8·26	...	7·9	8·78	8·4	8·2
July	...	7·91	7·63	...	8·06	...	8·04	7·23	7·32	...
August	...	...	...	7·92	7·4	7·26	6·76	6·96	6·8	
September	6·84	8·22	7·22	...	...	...	7·69	7·42		
October										
November										
All	7·76	8·46	8·1	8·07	7·9	7·26	7·59	7·57	7·5	8·2
Before July	8·22	9·32	8·75	8·27	8·26	...	7·9	8·78	8·4	8·2
After June	6·84	8·06	7·43	7·92	7·73	7·26	7·49	7·2	7·06	...
Total Average	Before July 8·45				(All 7·841)			After June 7·44		

40°.	70°.	71°.	72°.	73°.	74°.	75°.	76°.	77°.	78°.
April									
May									
June	7·97	8·06	8·66	8·31	8·98	...	8·36	...	8·15
July	...	7·12							
August									
September									
October									
November									
All	7·97	7·59	8·66	8·31	8·98	...	8·36	...	8·15
Before July	7·97	8·06	8·66	8·31	8·98	...	8·36	...	8·15
After June	...	7·12							
Total Average	Before July 8·35			(All 8·29)			After June 7·12		

Mr. Moul.

40°.	41°.	42°.	43°.	44°.	45°.	46°.	47°.	48°.	49°.
April	...	...	...	...	...	...	7·7	7·14	7·83
May	...	...	...	...	...	...	...	...	...
June	...	...	...	...	...	...	...	...	...
All	...	...	...	...	...	...	7·7	7·14	7·83
Total Average	(7·58)								

40°.	50°.	51°.	52°.	53°.	54°.	55°.	56°.	57°.	58°.	59°.
April	7·54	8·06	9·36	8·32	6·9	...	7·19	8·3	6·91	6·0
May	...	...	6·3	6·35	6·64	6·49	6·46	...	6·83	6·73
June	...	...	...	...	...	...	...	...	...	...
All	7·54	8·06	7·83	7·33	6·77	6·49	6·82	8·3	6·87	6·36
Total Average	(7·237)									

40°.	60°.	61°.	62°.	63°.	64°.	65°.	66°.	67°.	68°.	69°.
April	5·4	...	6·0	5·12						
May	7·6	6·76	7·08	6·97						
June	...	...	...	...	...	...	...	6·44	6·3	6·41
All	6·6	6·76	6·6	6·04	...	...	...	6·44	6·3	6·41
Total Average	(6·45)									

40°.	70°.	71°.	72°.	73°.	74°.	75°.	76°.	77°.	78°.
April									
May									
June	6·4	6·38	6·38	6·2	6·52				
All	6·4	6·38	6·38	6·2	6·52				
Total Average	(6·37)								

Thus it is proved indisputably that through long periods there is not a close correspondence, but, on the contrary, a wide difference in the relation between the degrees of temperature and the carbonic acid evolved; and that as the season advances towards autumn, with the same temperature or even with a certain decline of it, the carbonic acid progressively falls to a minimum. It is also evident that both before and after the period of change, viz. June, the respiration retains a certain amount of uniformity; and this at two different seasons will differ greatly, whilst it may be that the same temperature is found in both seasons. Thus my average quantities before July and after June respectively, in the four decades of temperature, differed as follows: 8·88 grs. and 8·21 grs., 8·69 grs. and 7·43 grs., 8·45 grs. and 7·44 grs., 8·35 grs. and 7·12 grs.—differences of upwards of 1 gr. of carbonic acid per minute in the three higher decades. Hence there is a want of uniformity in the progression of the decades, as before mentioned, due to the admixture of the results obtained in two seasons; whilst Mr. MOUL's returns are more uniform, since they comprehend scarcely more than the early season. Further, it is interesting to know that at each of the seasons the movements of temperature keep in advance of the movements in the carbonic acid quantities.

It now only remains to show that, even with sudden changes of temperature, there is not an exact relation between the temperature and the carbonic acid. The Table and Plate XXXIII. fig. 3, show this, first, in the proportion of carbonic acid to each degree of temperature; and secondly, the amount of diminution of carbonic acid with each increasing degree of temperature.

From the above we learn that as the temperature increased the carbonic acid decreased in an *increasing ratio*, and consequently that the two did not move in parallel lines. This is particularly well marked in my own case, in reference to both modes of inquiry, and in a very striking manner when the temperature exceeded 60°. Mr. MOUL's returns in the first series correspond with mine, but in the second they manifest the influence of some other disturbing cause.

Hence it appears that any attempts to find one uniform relation between the carbonic acid and temperature, such as that published by VIERORDT and LETELLIER, are exposed to serious error, and particularly if the inquiries, made upon different persons and in different seasons, are mixed together; and in reference to the influence of sudden changes of temperature, the variations in the carbonic acid in my experiments are greater than ·094 gr. per minute for each degree, as ascertained by VIERORDT. It is also quite evident that the changes are due to vital conditions, and not simply to the physical action of heat upon the body and the inspired air.

B. *Barometric pressure*.—The relations between barometric pressure and the carbonic acid expired are much less obvious than those of temperature; and although my returns have a general correspondence with those of VIERORDT, in showing that the relation is an inverse one, the rule is liable to many exceptions. Mr. MOUL's returns are more amenable to the law than mine, for they continuously declined from month to month, whilst the barometer rose; but in my case the month of May was exceptional. The lowest pressure was, however, in April, when the respiratory phenomena were very

active; and both were nearly uniform in July, August, and September, when the respiratory changes were low. To show, however, that there is no invariable relation, it may suffice to mention that with a pressure of 29·51 inches the carbonic acid was 8·19 grs. and 7·13 grs. in May and September respectively.

Thus, after a minute inquiry into the influence of these two agencies, there can be no doubt that the influence of season is far more than can be explained by these meteorological conditions, and that it is one which demands further accurate observation, and particularly in reference to the influence of light as it increases in intensity in the spring. It is, moreover, of the utmost importance to bear in mind that this influence is felt in every action of the system; for as the quantity of carbonic acid varies with the season, so do the quantities evolved under the influence of exertion and food. Hence, in stating the influence of any agent, it would be erroneous to give absolute numbers, under the idea that they would be true at all periods of the year. This is particularly applicable to the next subject of inquiry; for my experiments have shown that the same exertion, as for example walking at a given rate, *produces effects upon the respiration considerably greater in winter than in summer.*

[*Note, April* 1859.—Since the foregoing remarks were written, I have completed the observations during the cycle of the year ending March 31, 1859; and the quantity of carbonic acid evolved, with that of the air inspired and the rate of respiration, have been added to Plate XXXIV.

At the end of October the quantity of carbonic acid evolved had materially increased; and throughout November and December and the beginning of January the increase was progressive, so that the quantity had attained to upwards of 8½ grs. per minute. Throughout the remaining portion of January, as well as in February and March, the quantity evolved was nearly stationary, and even more uniform than at any other period of the year; but at the end of March it again increased, and on March 31, 1859, was very nearly the same as was recorded on March 31, 1858, viz. 8·25 grs. and 8·51 grs. per minute.

The quantity of air inspired per minute increased from an average of 395 cubic inches in October, to 414, 429, and 447 cubic inches in November, December, and January, in their order.

The rate of respiration in like manner increased on the average from 10·93 per minute in October, to 10·87, 11·15, 11·73, 11·35, and 11·38 in the months of November, December, January, February, and March, and did not reach to the elevation recorded in 1858.

The temperature after October remained, during the winter months, at averages varying from 43°·1 to 48°·9, and exhibited marked perturbations at the end of November and the beginning of January and March.

The monthly averages are appended to Table VI.

The variations observed from day to day were frequently attributable to the causes described in page 702, and tended further to corroborate the deductions then made; and

in further confirmation, it is remarkable to notice how frequently the evolution of carbonic acid increased on the Monday, after the rest and retirement of the preceding day.]

III. INFLUENCE OF WALKING AND THE TREADWHEEL.

The only experiments which I have been able to make in reference to exertion are limited to the influence of walking and the treadwheel.

1. *Walking.*

I employed two sets of the apparatus, and attached them to the mouthpiece by a long tube, partly of glass and partly of vulcanized india-rubber, so long as to enable me to walk about 11 yards in each direction. The distance was accurately measured, and the speed regulated with the watch in hand in the most exact manner. I also walked at the same speed for some time before the experiment began, so as to bring the body to the full influence of the increased action. The results are given in detail in Table VIII.

Table VIII.

Showing the influence of Sleep and Exertion.

Date.	Hour.	Carbonic acid, per min.	Air, per min.	Pulse, per min.	Rate of respiration, per min.	Temperature.		
						Wet.	Dry.	
	A.M. h m	grs.	cub. in.					
July 15 A.M.	1 30	5·7	......	......	......	67°	69°	*Whilst awake*, but after lying down for some hours, and with every approach to sleep.
	2 35	5·94	......	66	......	......	......	
	6 45	6·1	......	70	......	......	......	
July 16 A.M.	1 0	4·88	......	......	......	71	71	In *sleep*, but probably not profound.
	3 0	4·99	......	......	.....	......	......	In *sleep*.
	P.M.							
July 15 P.M.	3 30	18·1	799	90	14·5	72·5	75·5	*Walking* at 2 miles per hour.
	4 30	25·83	1028	......	16	......	......	*Walking* at 3 miles per hour.
	P.M.							
Oct. 8 P.M.	4 0	43·36	......	150	22	......	......	*Treadwheel*; 43 steps, ascending 28·65 feet per minute. I was on the wheel ¼ of an hour, and determined the carbonic acid for 3 minutes after 5 minutes, and the last 2 minutes of 15 minutes.
Oct. 9	3 30	42·9	......	150	21	......	......	*Treadwheel.* Determined the carbonic acid during 3 minutes after 5 minutes, and 2 minutes after 10 minutes.
	3 45½	......	1120	......	21	......	......	*Rest after treadwheel.* I sat down directly, and after ½ a minute used the spirometer. Another ½ minute was lost after 3½ minutes. The carbonic acid was collected— During 3 minutes after 4 minutes. During 2 minutes after 10 minutes. During 2 minutes after 13 minutes. 7 minutes.
	3 46½	......	930	......	18	......	......	
	3 47½	......	720	.....	17	......	......	
	3 49	......	680	......	17	......	......	
	3 50	......	590	......	16	......	......	
	3 51	.....	600	......	15	......	......	
	3 52	......	540	......	15	......	......	
	3 53	......	590	......	16	......	......	
	3 54	......	530	......	15	......	......	
	3 55	......	560	......	15	......	......	
	3 56	......	540	......	15	......	......	
	3 57	......	500	......	15	......	......	
	3 58	9·14	560	......	15	......	......	
	3 59		520	102	15	......	......	
Oct. 22	4 0	48·66	......	150	20	......	......	Dined on prison fare at 2½ P.M.; soup and bread. *Treadwheel*, 40 to 44 steps per minute. Carbonic acid taken three times in the last two of each 5 minutes.

On July 15, with a temperature of $75\frac{1}{2}°$, whilst walking at two miles per hour, I expired 18·1 grs. of carbonic acid per minute, with a rate of respiration of $14\frac{1}{2}$, and of pulsation 90 per minute, and with 799 cubic inches of inspired air per minute.

At three miles per hour the carbonic acid was increased to 25·83 grs., the air to 1027·5 cubic inches, and the rate of respiration to 16 per minute. I did not attempt a greater speed; for it required closer attention than I could give to the speed and the apparatus at the same time to maintain a uniform rate of more than three miles per hour.

Thus, taking as a basis of comparison the system at rest and without food, in the sitting posture, at the same hour, viz. 7·44 grs. of carbonic acid per minute, the effect of walking at two miles per hour was 2·5 times as great, and at three miles per hour 3·5 times. There is a curious progression in the relation of carbonic acid to the inspired air under these different conditions, as follows, taking 1 gr. of carbonic acid as the unit of comparison: viz. in rest, sitting, and fasting, 1 : 49·6 cubic inches; walking at two miles per hour, 1 : 44·1 cubic inches; at three miles per hour, 1 : 39·7 cubic inches—a progressive increase in the ratios of nearly one-ninth of the basis quantity.

2. *The Treadwheel.*

The treadwheel is a kind of exertion which consists in lifting the body a given height in a given time, from the steps of a wheel turning downwards, and holding it in a position in which its centre of gravity is anterior to its perpendicular central line. My experiments have been made in many county gaols, but in only that at Coldbath Fields have I determined the quantity of carbonic acid evolved during this kind of exertion. I am under obligation to the Governor and Visiting Justices for much courtesy and assistance.

There are not any similar inquiries on record; but in reference to raising the body through a given space at given times, LAVOISIER has stated the quantity of oxygen which is consumed, and also that the increased rate of pulsation is directly as the weight multiplied by the height, if the effort is an easy one.

The influence of the treadwheel has been determined by three experiments, as recorded in Table VIII. On October 8, with a low normal state of the respiration, I expired 43·36 grs. of carbonic acid per minute whilst upon the wheel; and on October 9 the quantity was 42·9 grs. per minute. On each occasion the pulse was 150 per minute, and the rate of respiration 22 and 21 per minute respectively. On October 22, in the afternoon, after having eaten the prisoners' dinner of brown bread and soup, the quantity was 48·66 grs. per minute, with a pulsation of 150, and respiration 20 per minute. In all the inquiries I worked the wheel fifteen minutes at a time. In the two former I collected the carbonic acid during three minutes, after having been upon the wheel five minutes, and again during the last two of the fifteen minutes; but in the last inquiry I collected it in the last two of each five of the fifteen minutes. Thus the average in the first two is derived from five minutes, and in the last

from six minutes. I was unable to use the spirometer as well as the analytical apparatus whilst working the wheel, for I found the breathing too much oppressed by it; and more particularly, since I was compelled to use a double set of the analytical apparatus, on account of the rapidity of the current of the expired air which was forced through it.

After the second inquiry, I determined the state of the respiration in the fifteen minutes constituting the interval of rest. After leaving the wheel I sat down (after the manner of the prisoners), and with a loss of half a minute used the spirometer, and noted the quantity of air inspired per minute. The carbonic acid was also collected during seven minutes; viz. during three minutes after four minutes' rest, two minutes after ten minutes', and two minutes after thirteen minutes' rest. The average quantity of carbonic acid thus obtained was 9·14 grs. per minute; but that does not include the first four minutes of the period of rest, and the following statement shows that then the respiration was fast subsiding to the minimum quantity. From a consideration of the quantity of air inspired, I compute that the quantity of carbonic acid evolved during the first minute of rest was 25 grs., in the second 20 grs., and in the third 15 grs., and hence that the average of the whole fifteen minutes' rest was 11·3 grs. per minute.

The quantity of air inspired in cubic inches per minute, commencing half a minute after the labour had terminated, was as follows, in each minute, in its order:—1120, 930, 720, 680, 590, 600, 540, 590, 530, 560, 540, 500, 560, and 520, yielding an average of 641 cubic inches per minute. It is evident that whilst there is, during the whole interval of rest, an increase in the respiratory changes over that of rest apart from this exertion, the great excess due to the exertion disappears after five minutes' rest.

The remark made already as to the influence of season over the effect of exertion must not be forgotten.

Résumé.

In the foregoing paper it has been shown—

1. That it is possible to collect the whole of the carbonic acid exhaled by the lungs in the twenty-four hours, or for any period, however long or short.

2. The quantity of carbonic acid expired in the twenty-four hours was, on the average of eight sets of inquiries in four adult males when in a state of rest, 26·193 oz. (7·144 oz. carbon), of which 1950 grs. were expired in the six hours of the night. The proportion per minute in the night and the day is 1 to 1·84. In light sleep 4·88 grs. per minute were exhaled, and 4·5 grs. is the estimated amount in profound sleep in July. The quantity of carbon exhaled in the twenty-four hours, by each of the subjects at rest, was 5·6 oz., 6·54 oz., 6·735 oz., and 7·85 oz.

3. The quantity of air inspired during the working day of eighteen hours, was, to the carbonic acid expired, an average of 56·3 cubic inches to each grain.

4. The rate of respiration was on the average 13·87, and of pulsation 71·7. The average depth of inspiration was 33·6 cubic inches.

5. The factor of the respirations to equal the number of the pulsations varied in the different persons, increasing with their age, from 4·63 to 5·72, and on the average was 5·15.

6. Half of the product of the respirations and pulsations very nearly equalled the number of cubic inches of air breathed in several of the cases. No such numerical relation could be found in reference to the carbonic acid.

7. The variations of the carbonic acid in the same day, with food, were so great as an average of 10·43 grs. and 6·74 grs., and extremes of 6·96 grs. and 13·3 grs.; but in a prolonged fast the extreme difference was less than 1 grain.

8. In a prolonged fast of twenty-seven hours, the diminution per cent. from the quantities on a day with food, was 25 of carbonic acid, 30 of air, 37 of vapour, ·7 of rate of respiration, and 6 of rate of pulsation. The loss of carbon in the twenty-four hours is equal to that contained in 20 oz. of bread. The returns were so uniform, that the quantity of carbonic acid expired at the end of twenty-seven hours was the same as at 4½ hours after food.

9. There is a normal or basal line below which the system does not pass in health and wakefulness, and which is tolerably uniform. It is the same in the complete abstinence from food, as at the end of the interval between meals. There is also, when at rest, a higher point, which the system does not exceed, due to food, and it is the highest after breakfast and tea.

10. There is an increase of carbonic acid in the absence of food, at or near to the period when it usually increased with food.

11. There are variations from day to day, in the absence of food and exertion, which are dependent upon the amount of waste and supply of the preceding day and night. *Cæteris paribus*, the more food, rest, and sleep, the greater will be the quantity of carbonic acid evolved on the following morning.

12. There are great variations from season to season, so that, as the hot season advances, all the respiratory phenomena are lessened. The diminution in myself at the middle of August was 30 per cent. of air, 32 per cent. in rate of respiration, and 17 per cent. of carbonic acid. In Mr. Moul, to the middle of June the diminution was 27 per cent. of air and also of carbonic acid, and 28 per cent. in the rate of respiration.

Spring is the season of the greatest, and the fall, of the least activity of the respiratory and other functions.

13. Temperature and atmospheric pressure only partially explain the effect of season; for with the same temperature, at different seasons, there is great diversity in the carbonic acid expired, and particularly with a medium temperature; as, for example, 59°, with which the quantity of carbonic acid was 9·13 grs. in the spring, and 6·76 grs. in the summer and autumn. The relation of temperature and pressure to the carbonic acid is an inverse one, the former acting in an *increasing ratio* in cases of sudden increase, and with so much power that 2·3 grs. of carbonic acid per minute were lost in seven days.

The period of permanent decline in the carbonic acid is May and June, in different persons, and at the period of minimum quantity there is the greatest uniformity. Temperature moves in advance of the carbonic acid, and particularly as it declines.

14. All respiratory phenomena vary with the season, and hence it is better to adopt comparative rather than absolute quantities—the comparison being with the state of rest, with or without food; but the latter is the most reliable.

15. The effect of walking, compared, 1st, with the average state of rest with food, and 2ndly, with the state of system at rest before the breakfast, and therefore whilst fasting, is as follows:—at two miles per hour, one hour is equal to $1\frac{4}{5}$ hour with food, and to $2\frac{1}{2}$ hours without food. At three miles per hour, one hour to $2\frac{3}{4}$ hours and to $3\frac{1}{2}$ hours. One hour of the labour of the treadwheel, whilst actually working the wheel, is equal to $4\frac{1}{2}$ hours with food, and 6 hours of rest without food. The proportion of carbonic acid to the inspired air is much greater with exertion than at rest; and it increases as the speed, in a progression of one-ninth of the quantity at rest for two and three miles per hour without food.

16. The proportion of the carbonic acid to the inspired air is greater without than with food, and in summer than in winter. It is not absolutely uniform at any time, and it differs in different persons.

Men differ in every subject which has been investigated.

In conclusion, I beg to offer my warmest thanks to Mr. Moul, to Professors Frankland, Playfair, Sharpey, and Williamson, and other gentlemen who have aided in these and other inquiries.

Explanation of the Plates.

PLATE XXXIII.

Fig. 1. Shows the quantity of carbonic acid evolved per minute, with and without food, in contrast, and also the effect of the supper on March 12, as contrasted with the absence of that meal on May 15. The observations delineated in the morning of the day of fasting in July followed, and did not precede those represented in the afternoon.

Fig. 2. Represents the daily diminution in the quantity of carbonic acid per minute, with sudden increase in temperature in April 1858. The diminution in the quantity of air inspired by Mr. Moul is also stated on each day.

Fig. 3. Exhibits the same fact in two other aspects, viz. the quantity of carbonic acid in decimals of grains per minute to each degree of temperature, and also the diminution in the expiration of carbonic acid in decimals of grains per minute for each degree of temperature above that which occurred immediately before the increase of temperature took place.

PLATE XXXIV.

Shows the quantity of carbonic acid expired, and of air inspired, per minute, with the depth of inspiration, and the frequency of pulsation and respiration at the same hour, and under the same circumstances, on about 200 mornings in the year, in relation to the temperature, with the wet and dry bulb, and the season of the year. There were two subjects for experiment until the middle of June. The opposition of sudden changes of temperature, and the expiration of carbonic acid, is best seen from April 14 to 28. The progressive seasonal diminution in the expiration of carbonic acid commences at the beginning of June and ends in September, from which period the progressive increase occurs until January, and thenceforward the quantity is shown to be nearly uniform.

FIG. I.

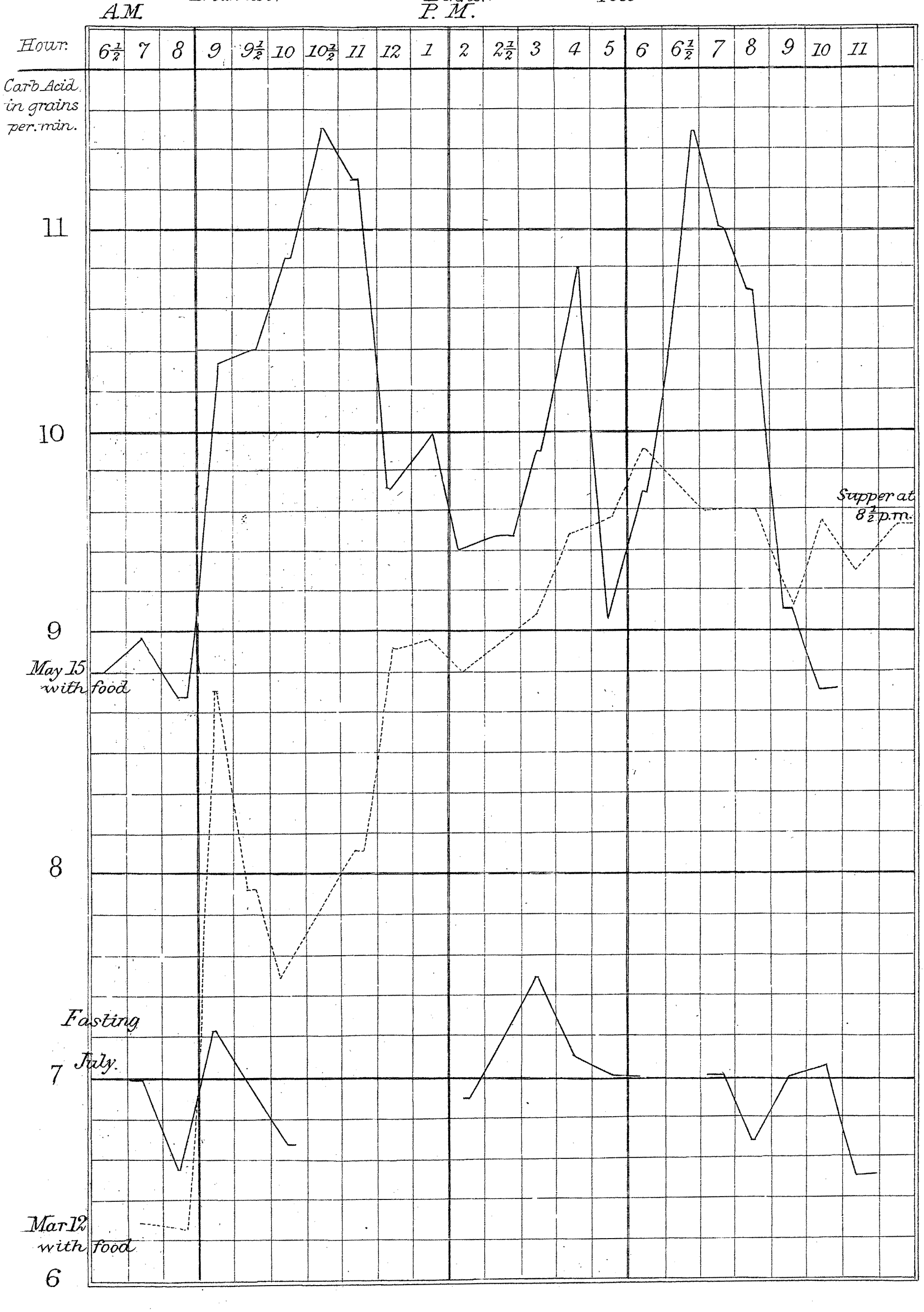


Diagram shewing the quantity of Carbonic Acid evolved during the day with food on two occasions and without food on one occasion. 1858

FIG. 2.

Relation of Temperature & Carbonic Acid on April 13th to 27th 1858.

Temp:		49°	47·5°	54°	58·5°	58°	60·5°	62·5°	62·6°	63·6°	59·°	58°
Carb: Acid grains per min.	Self	9·34	9·46	8·14	8·3	8·4	8·08	8·04	8·76	8·4	8·11	9·3
	Mr Moul		7·7	6·9	7·2	7·	5·4	6·62	5·38	5·12	6·	6·52
Air. Cub. Inches per min.	Mr Moul		482	438	444	400	298	394	306	348	392	394

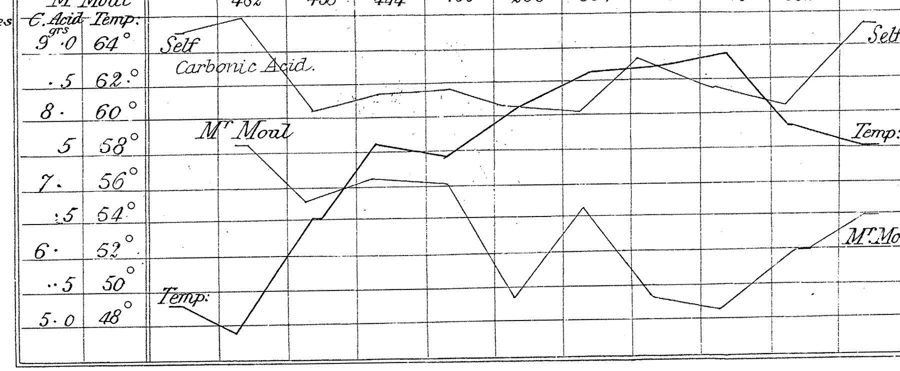


FIG. 3.

Relation of Carbonic Acid to Temperature 1858.

April		14	15	16	20	21	22	23	24	26	27
Temp:		47·5°	54·°	58·5°	58·°	60·5°	62·5°	62·6°	63·6°	59·°	58°
Carb: Acid (in grains per min.) to each degree of Temp:	Self	·2	·15	·142	·144	·133	·128	·14	·132	·137	·16
	Mr M.	·162	·127	·123	·12	·04	·105	·07	·13	·1	
Carb: Acid (in grains per min.) lessened with each degree of Temp: above 47·5°	Self		·2	·1	·1	·1	·093	·046	·065	·128	Averages ·104
	Mr M		·12	·045	·066	·177	·072	·153	·098	·148	·11 ·109

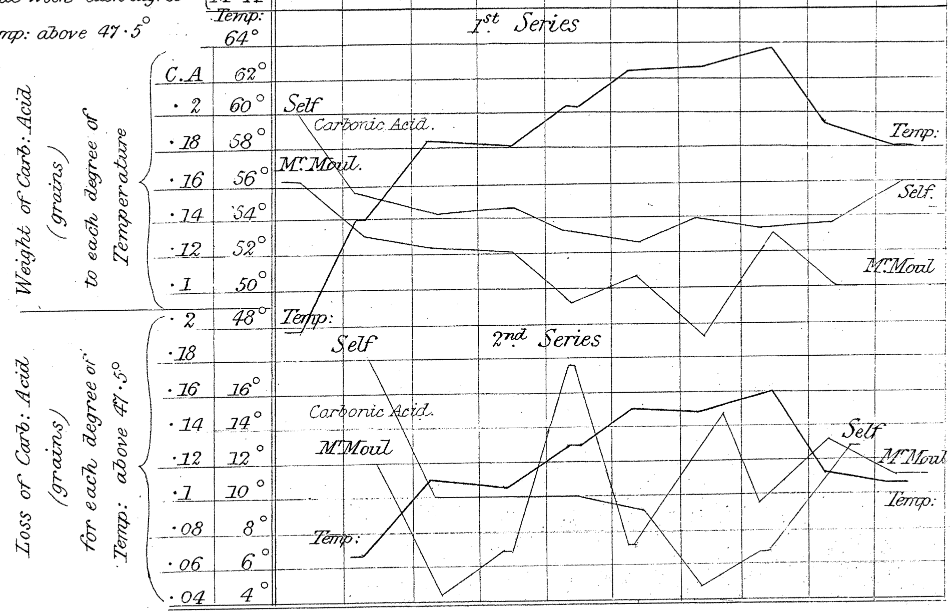


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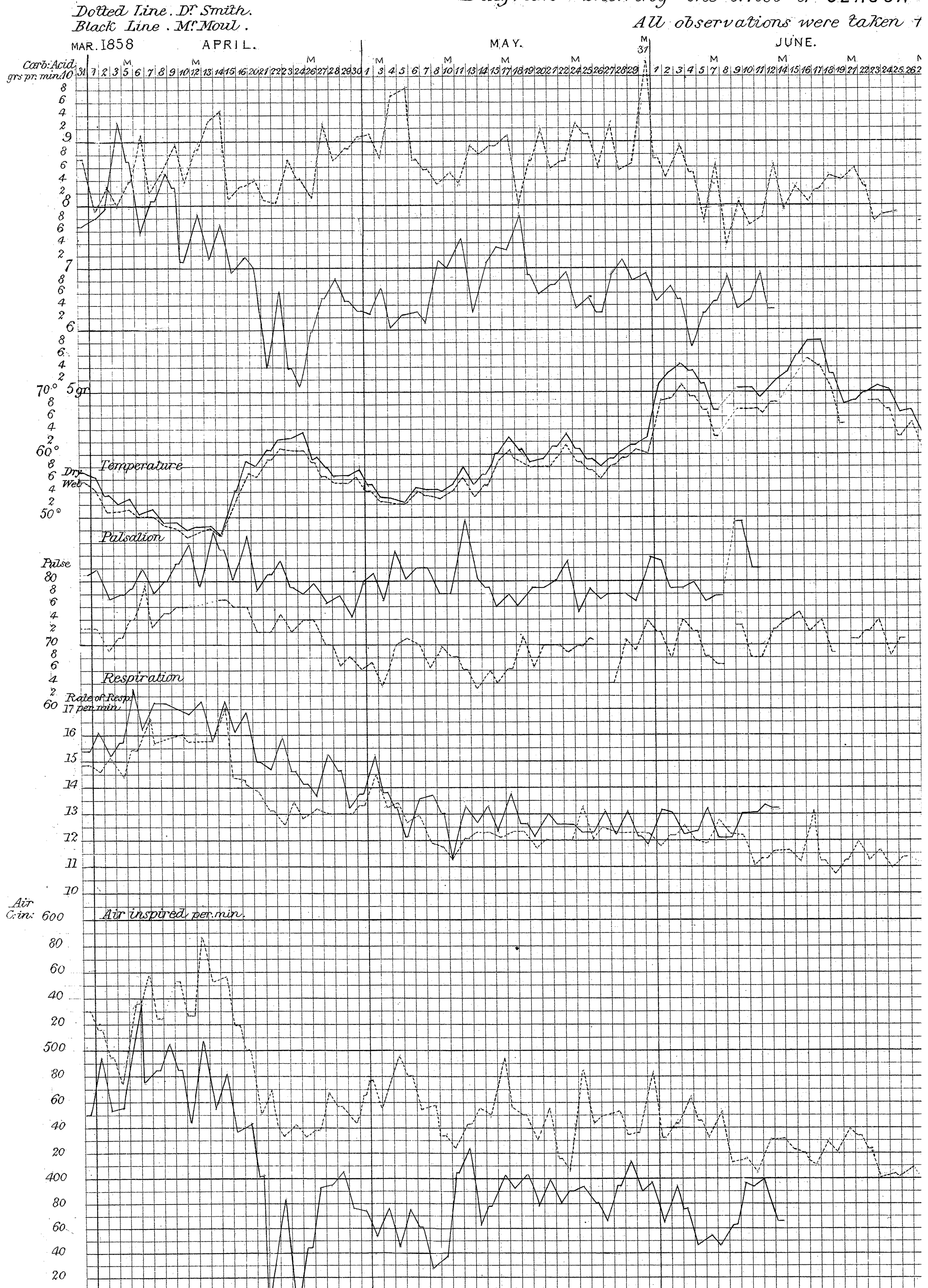
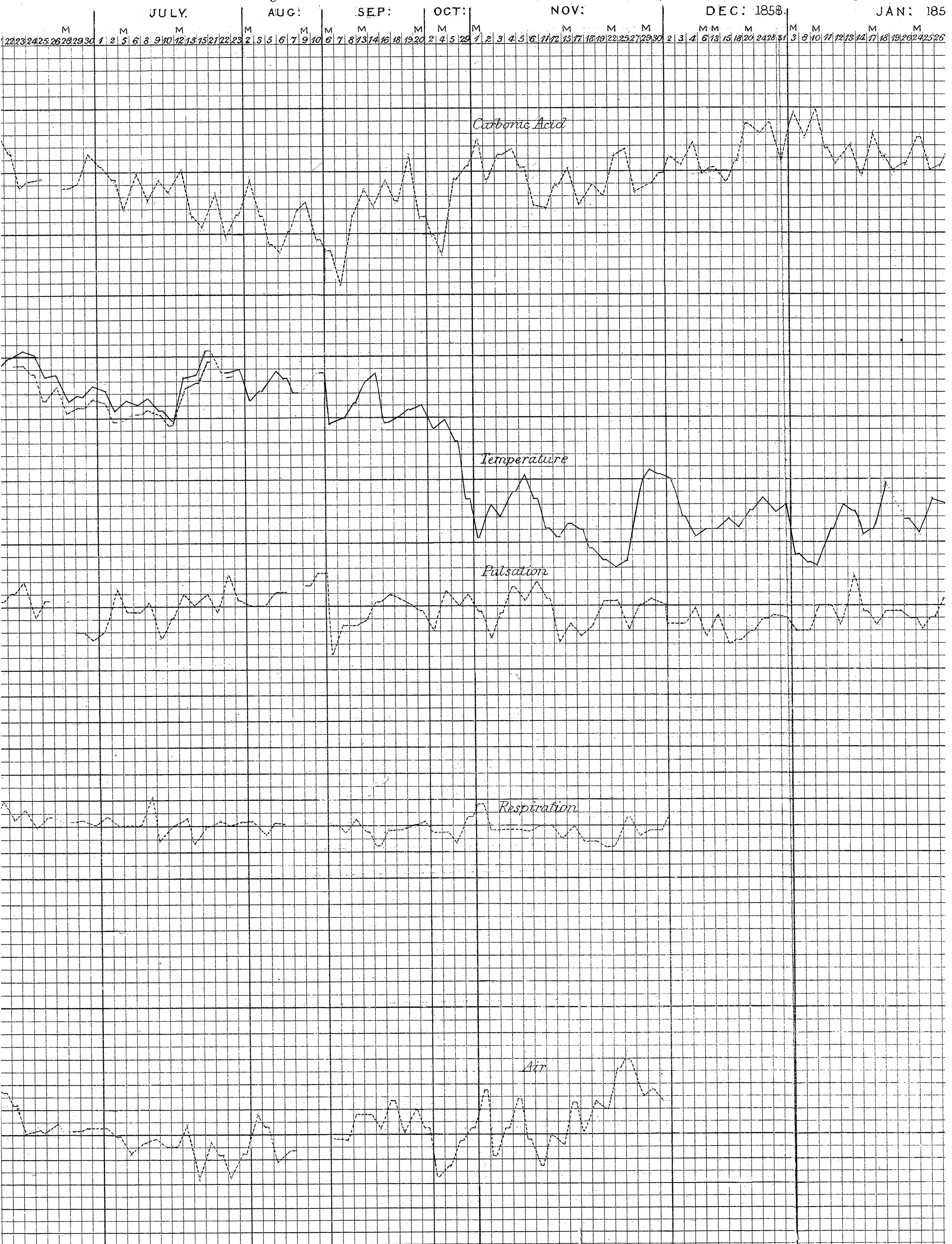
Diagram Shewing the effect of SEASON

All observations were taken f

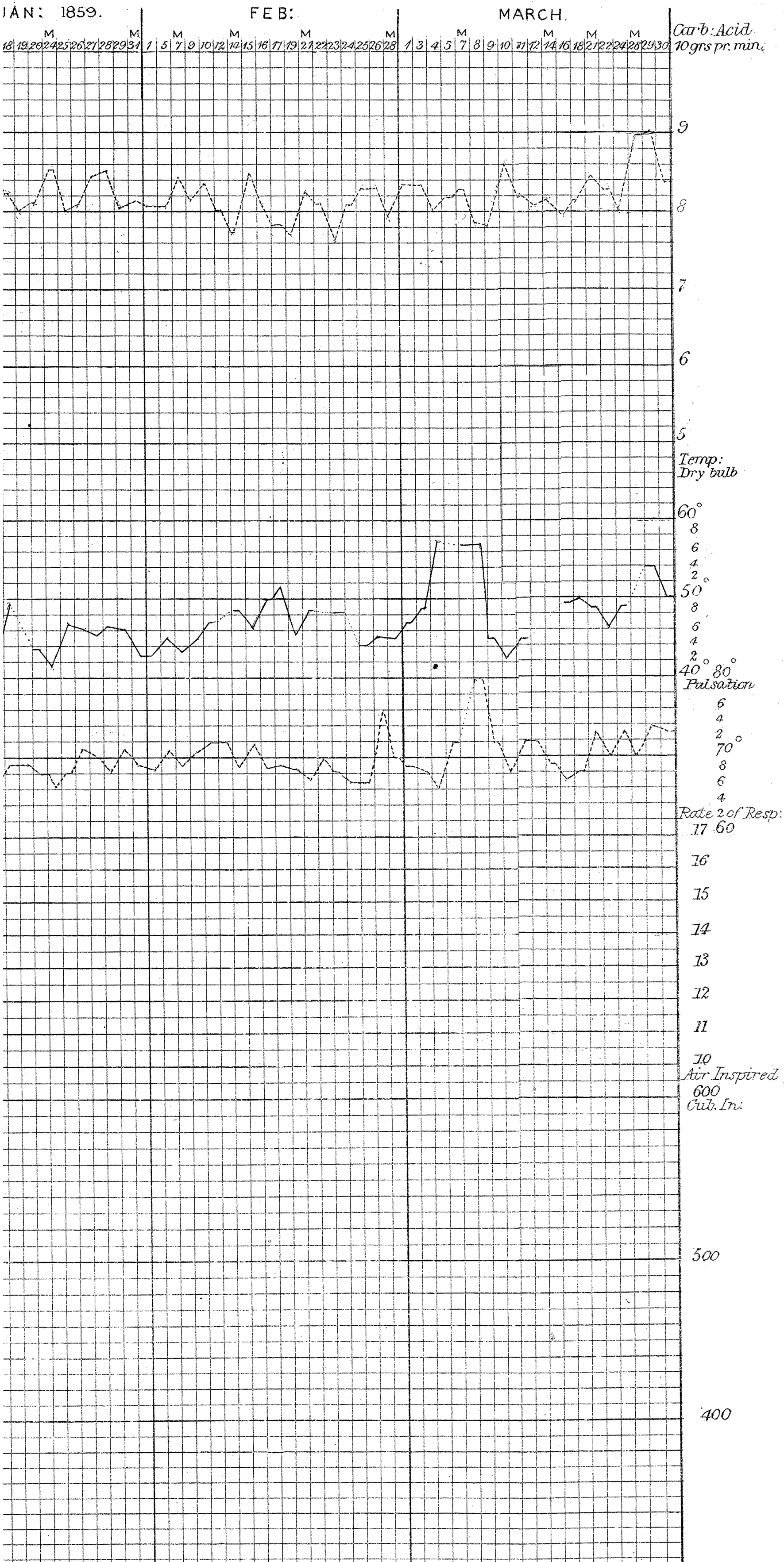


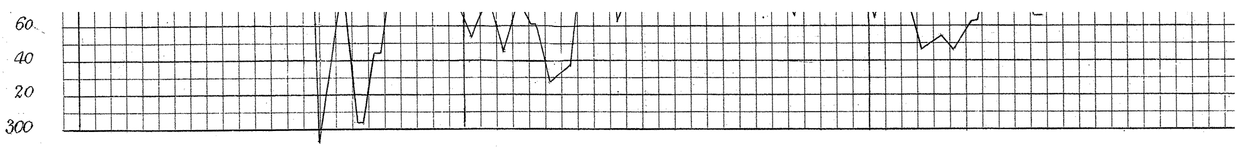
...ASON on the Respiration & Pulsation from a Series of Observations made throughout th...

...aken from 7 to 8 A.M. fasting until Oct.r after which they were taken at 9. A.M. still fasting.



out the Year.


JAN: 1859.
FEB:
MARCH.
Carb: Acid. 10 grs pr. min.
9
8
7
6
5
Temp: Dry bulb
60°
50°
40°
80°
Pulsation
70°
Rate of Resp:
17
60
16
15
14
13
12
11
10
Air Inspired 600 Cub. In:
500
400


60
40
20
300

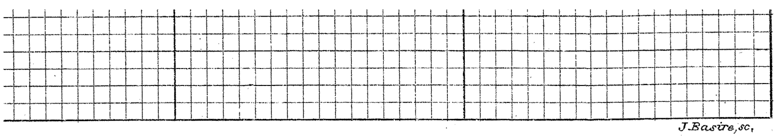


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Diagram Shewing the effect of SEASON on the Respiration & Pulsation from a Series of Observations made throughout the Year.

All observations were taken from 7 to 8 A.M. fasting until Octr. after which they were taken at 9. A.M. still fasting.