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RESEARCHES UPON RESPIRATION,

MADE IN THE PHYSIOLOGICAL LABORATORY OF JEFFERSON MEDICAL COLLEGE.

—BY—

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No. 1.

ON THE CONSUMPTION OF OXYGEN AND THE PRODUCTION OF CARBON DIOXIDE IN ANIMALS.

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RESEARCHES UPON RESPIRATION.

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No. 1.

On the Consumption of Oxygen and the Production of Carbon Dioxide in Animals.

Of all subjects of biological enquiry there is none, perhaps, that has attracted more attention or exceeds in importance that of the accurate determination of the consumption of oxygen and production of carbon dioxide and water in man and animals. Not only is the proper ventilation of our dwellings, lecture rooms, theatres, halls of justice, based upon such knowledge but all estimates as to the amount of radiant energy set free through the combustion of food, as determined by calorimetrical experiments, are dependent upon the same. Passing over the early observations of Boyle, Hales, Cigna, Black and Priestley which showed that the air becomes so materially modified by animals breathing it as to soon render it irrespirable unless renewed, it may be said that Lavoisier, by his classical researches, first established (1785) the modern theory of respiration and calorification, namely, that the carbon dioxide and water produced during respiration and the heat thereby set free are due to the oxidation of the carbon and hydrogen of the food. While subsequent investigations, such as those of Allen and Pepys, Milne Edwards, Despretz, Dulong, Valentin and Brunner, Boussingault and Barral, confirmed in the main the profound views announced by Lavoisier, nevertheless the differences in the results obtained were such as to induce Regnault and Reiset[1] to undertake an extended series of researches upon the respiration of different animals, more particularly with the view of determining the amount of oxygen consumed and carbon dioxide produced. The results of this elaborate investigation, it may be added, have never, in the main, been questioned. Inasmuch, however, as the water exhaled by an animal is not determined by the Regnault-Reiset apparatus, and in so far as known to the authors they are the only experimenters who have ever had the opportunity of comparing the amount of oxygen con-

[1] Recherches Chimiques sur la Respiration des animaux des diverses classes. Par MM. V. Regnault et J. Reiset, Annales de Chimie et de Physique, 3me Ser., tome XXVI, 1849.

sumed as so determined directly, with the amount absorbed as determined indirectly from the carbon dioxide and water produced, as obtained by means of a Voit respiration apparatus, it does not appear superfluous to submit the results of experimenting with the two kinds of respiration apparatus.[1]

Description of Apparatus.

The Regnault-Reiset respiration apparatus in the fulfilment of the physical and chemical requirements incidental to the construction of such apparatus, remains to this day unsurpassed. It consists essentially of the following three parts:

A central glass bell-jar or chamber for the reception of the animal, communicates on the one side with two glass pipettes containing an alkaline solution for the absorption of the carbon dioxide produced by the animal, and on the other side with a glass pipette filled with oxygen to replace that absorbed by the animal in the bell-jar.

The central glass bell-jar or chamber A, Pl. I, tubulated above and having a capacity of about 47.6 litres,[2] is cemented through its lower open portion into the inner of two grooves with which the iron-plate upon which it rests is provided. The metal plate itself presents a central opening sufficiently large for the introduction of the animal into the chamber and is hermetically closed (the animal having been introduced) by means of a circular-metal lid, the latter being tightly screwed up to the under surface of the plate by means of bolts. The inner circular portion of the metal plate and upper surface of the metal lid closing the inferior opening of the central bell-jar are painted with red lead so as to avoid any absorption of oxygen through oxidation of the metal. In order that the animal should not stand directly on the circular metal disk closing the inferior opening of the central bell-jar (which would cool it too much) a movable bottom consisting of a circular wooden disk pierced with holes upon which the animal is placed is passed up

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[1] The results obtained by Voit's respiration apparartus will be presented in a subsequent communication.

[2] The absolute capacity of the jar or that of the tubes connecting it with the pipettes need not be determined since the investigation, is based upon a comparison of the composition of a given amount of the air within the jar at the beginning and at the end of the experiment and any extra amount of air within the jar as well as that in the connecting tubes can be neglected, as they are on both sides of the equation.

through the inferior opening of the bell-jar. This can be easily done as the wooden disk is somewhat smaller than the inferior opening of the jar. The circular wooden disk with the animal placed upon it, after being introduced through the inferior opening of the chamber is, slightly rotated and then lowered and comes to rest upon three pivots projecting inwardly over which the disk glides, it being sufficiently notched upon its sides for that purpose. If it be desired to preserve the urine and feces this can be accomplished by placing a circular metal pan within the space between the under surface of the wooden disk and upper surface of the iron lid closing the inferior opening of the jar into which space the excreta would otherwise fall. The central glass bell-jar or chamber, A Pl. I, with a thermometer suspended within it and containing the animal resting upon the wooden disk, the inferior opening of the jar being closed by the iron lid, is surrounded by water, the latter being held by four rectangular glass plates fitting into the outer of the two grooves with which the iron plate is provided. As it is essential that the temperature of the central bell-jar containing the animal should be maintained as constant as possible, that of the water surrounding it must be maintained equally so.

Through the upper superior portion of the central bell-jar, A Pl. I, pass four tubes L M N O. Through the tube L the jar communicates directly with the flask P containing a solution of soda or potash and indirectly with the pipette F containing the oxygen to be respired. By means of the tube M and the small mercurial manometer connected with it the pressure of the gas within the jar A can be determined from moment to moment. Through the two connecting tubes N O the jar A communicates with the two pipettes R S containing the alkaline solution for the absorption of the carbon dioxide. The accessory tube T given off from the main tube O and leading to the large mercurial manometer enables us, as we shall see presently, to draw out of the jar A a sample of gas for analysis. The iron plate with the bell-jar A is firmly supported by a heavy frame-work resting upon the floor. The two glass pipettes, Pl. I, R S, serving for the absorption of the carbon dioxide, connected through their lower extremities by an india-rubber tube and having a capacity of about three litres, are filled with a solution of caustic soda or potash whose weight and composition have been previously determined. The two glass pipettes R S are firmly attached to two metal supports. The supports are suspended by chains from the beam V and with the movement of the latter alternately ascends and descends uniformly in a vertical manner the supports moving in a frame. The beam V is moved by the eccentric X which in turn is moved by the rotation of a number of interlocking toothed wheels W the movement of the latter being due to the fallof 150 kilogrammes, through 10 metres and regulated by a fan. The relations of the wheels, weight, etc. are such as to necessitate the winding up of the weight once only in fifteen hours. The vertical movement of the pipettes just described is such that as the pipette R, for example, ascends, the solution of soda within it passes into the pipette S which descends; the air in the latter freed of its carbon dioxide passing into the jar A while the air of A loaded with carbon dioxide passes into the pipette R. On the other hand, as the pipette S ascends and R descends, the solution of soda passing from S to R, the air of the pipette R, freed of its carbon-dioxide, passes back to the jar A and the air of the latter, loaded with carbon dioxide, passes into the pipette S. In order that the absorption of the carbon dioxide by the soda be as thorough has possible a number of glass tubes, open at both ends, are placed within the pipettes, the walls of these tubes remaining moistened with soda when the pipettes have emptied themselves of the alkaline solution. They present consequently a large absorbing surface. It will be observed that as the pipette S takes air from the upper portion of the jar A and the pipette R from the lower portion, the play of the pipettes not only ensures the absorption of the carbon-dioxide in proportion as it is produced by the animal but keeps up a continual agitation of the air within the jar A which tends to maintain its composition uniform. The frames in which the glass pipettes move, together with the wheels etc. moving them, are firmly supported by a heavy metal frame-work resting upon the floor. The pipette,[1] F Pl. I, filled with oxygen by means of the tube *d*, replacing that of the jar A absorbed by the animal, has a capacity of 19,440 c. c. between the marks *b* and *c* and it communicates through its upper opening and with the flask P which in turn communicates with the jar A and, through its lower opening with a vessel *e* which receives the liquid that flows out of the pipette

[1] In the original experiments as performed by Regnault and Reiset three oxygen pipettes similar to the one described above were successively used, the experiment lasting until the last pipette was exhausted. It was found, however, by the authors, though provided with the three pipettes, that it was easier on account of the connections to refill the same pipette when necessary than to substitute for it a second pipette previously filled.

F, when the latter is filled with oxygen, and with the tube *f* into which the liquid flows that drives the oxygen out of the pipette over into the jar A. The oxygen made use of by the authors was obtained by heating in an iron retort a mixture of chlorate of potassium and black oxide of manganese and passing the gas so developed through a solution of caustic potassa. The gas so purified and further tested by explosion with hydrogen, appeared to be pure. In order to introduce the oxygen into the pipette previously filled with a concentrated solution of calcium chloride, little or no oxygen being absorbed by that liquid, the stop cock on the upper tube *d* putting the oxygen reservoir in communication with the pipette and that on the inferior tube *j* conducting the fluid away, must be opened, and as the oxygen passes into the pipette the solution of the calcium chloride flows out into the vessel *e*. The pipette should be filled under a little higher pressure than that of the atmosphere and the gas allowed to acquire the same temperature as that of the latter. By allowing a little oxygen to escape and so making its elastic force equal to that of the atmosphere, the level of the solution of calcium chloride can be brought to that of the lower mark *c*. The height of the barometer and the temperature of the oxygen must now be noted, the latter being ascertained by means of a thermometer suspended within the pipette.

After this somewhat detailed description of our respiration apparatus let us endeavor to describe the manner of conducting the experiments.

Method of Experimentation.

The oxygen pipette being filled under the atmospheric pressure H and a temperature t let V represent the capacity in litres of the pipette between the upper and lower marks and *f* the pressure of the aqueous vapor abandoned to the oxygen by the solution of calcium chloride, then the weight W of the oxygen delivered to the bell-jar supposing the pipette to be emptied to the lower mark,[1] will be given by the equation

[1] In order to be able, if necessary, to stop the experiment at any moment the pipette was graduated in litres and demilitres Owing, however, to the uncertainty as to the accuracy of the graduation incidental to the globular form and large size of the pipette it is undesirable to terminate the experiment before the pipette has emptied itself to the upper mark.

$$W = 1{\cdot}4298\ V \frac{1}{1 + 0{\cdot}00367\ t} \times \frac{H - f}{760}$$ [1]

The pressure of the vapor from the calcium chloride solution to be deducted from the barometric pressure, was accepted by the authors as being from 0·47 to 0·55 of the pressure of aqueous vapor at corresponding temperatures according as the temperatures of the oxygen varied from 16° C to 21° C, the experiments being made in winter or summer.

The pipettes for absorbing the carbon dioxide are now weighed and then filled with a solution of caustic potash or soda and then again weighed, the difference giving the weight of the solution, the amount of carbon dioxide present in the soda having been previously determined by analysis, the method of which will be described presently. The animal is now introduced, with food and drink if necessary, into the bell-jar, the walls of which have been previously moistened. In order to maintain the temperature of the water surrounding the bell-jar as constant as possible, the experiment should begin with the temperature of the water a little higher than that of the surrounding atmosphere, the heat given off by the animal compensating for that given off by the water. The lid closing the inferior opening of the jar is now screwed up and the two-way stop cocks so turned that the interior of the bell-jar is put in communication with the interior of the oxygen pipette through the intermediation of the flask P but cut off from the atmosphere, and the carbon dioxide pipettes put in motion through the descent of the weight. Let us suppose that the respiration of the animal consists simply in the consumption of oxygen and production of carbon dioxide. It is evident that in proportion as the oxygen of the chamber is consumed by the animal and the carbon dioxide produced is absorbed by the soda of the pipettes, the elastic force of the gas within the chamber is diminished and, if the chamber communicates with the oxygen pipette, the oxygen absorbed will be at once replaced by an equivalent amount of oxygen, provided that the solution of calcium chloride be added through the tube *f* to that in the oxygen pipette in quantity sufficient to maintain the elastic force of the gas equal to that of the

[1] The number 1·4298=weight of 1 litre of oxygen at standard pressure and temperature.

0·00367=coefficient of expansion for each deg. C.

760.=standard barometric pressure in millimetres of mercury.

atmosphere. This successive addition of the solution of calcium chloride is accomplished by putting the tube of the oxygen pipette in communication with the reservoir G containing a concentrated solution of calcium chloride, the level of which is maintained very nearly constant by means of the three glass flasks 1, 2, 3 filled with the same solution and which empty themselves successively as the level of the fluid in the reservoir falls, the flasks differing slightly from each other in the length of their necks. In proportion as the oxygen in the pipette becomes rarefied the liquid column in the tube falls and the elastic force of the air in the tube diminishes, the consequence of which is that the solution of calcium chloride flows from the reservoir into the tube and thence into the pipette. Nevertheless the elastic force in the chamber does not remain constant during the time that the pipette furnishes oxygen. It diminishes in proportion as the pipette becomes filled with the solution of calcium chloride, that is if such solution was at the same level in the tube and the pipette at the moment that the former was cemented to the tube leading from the reservoir, the pressure of the air within opposing the flow from the reservoir[1]. As a matter of fact, however, the variations due to the cause just mentioned may be restricted to very narrow limits by simply raising the level of the solution in the tube a few inches higher than that of the solution in the pipette before joining the tube to that leading from the reservoir. By so doing an excess of pressure of the gas within the chamber of about 1 centimeter is maintained which is of advantage in compensating for the small amount of carbon dioxide 1 to 2 per cent always present in the chamber notwithstanding the constant play of the pipettes for the absorption of the latter. It should be mentioned, however, in this connection that absolute constancy of pressure can not be maintained since variations in barometric pressure modify that of the gas within the chamber. Towards the end of the experiment, when there only remains about 300 cubic centimeters of oxygen in the pipette, the tubes are disconnected and the solution of calcium chloride poured into the tube until the solution in the pipette rises to the level of the upper mark when the stop cock on the tube is turned off. By this time there is an excess of pressure within the chamber of about 2 to 3 per cent and while the oxygen corresponding to this ex-

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[1] That such is the case is shown by disconnecting the tubes for a moment after the flow from the reservoir has ceased, for in connecting them again the flow at once begins.

cess is consumed by the animal, plenty of time is afforded for making the temperature of the water and therefore of the chamber the same as at the beginning. By observing the fall of the mercury in the gauge the requisite number of millimetres of mercury is obtained which, if added to or subtracted from the observed barometric pressure, makes the final equal to the initial pressure.[1]

During this time also a sample of the gas of the chamber is drawn off for analysis.

In order to draw off a sample of gas from the chamber for analysis the tube already referred to as being given off from the tube T is put in communication with the large mercurial manometer. In this case as the mercury flows out the gas flows into the manometer whence, as will be presently described, it is transferred for analysis to the Hempel burettes. It is indispensable that the sample of gas should be drawn from the chamber as the pipette R ascends, inasmuch as at that moment the gas of the chamber loaded with carbon dioxide passes into that pipette and consequently into the manometer. If the sample was drawn as the pipette descends, the gas so obtained being freed of its carbon dioxide would not represent the composition of the gas within the chamber. The sample of gas having been drawn from the chamber at the moment that the pressure of the gas was the same as at the beginning of experiment the movement of the pipettes for the absorption of the carbon dioxide is stopped. The animal is removed and weighed together with food and excreta and the pipettes at once also weighed. The increase in weight of the pipettes at the end of the experiment as compared with their weight at the beginning represents both the carbon dioxide absorbed and the hygrometric water fixed by the concentrated solution of soda. The weight of the carbon dioxide contained in the solution of soda is then determined by analysis and deducting therefrom the the weight of the carbon dioxide that the solution contained at the beginning of the experiment as previously determined, the difference will be the weight of the carbon dioxide absorbed during the experiment by the solution of soda. This weight added to that of the carbon dioxide remaining in the chamber at the end of the experiment as determined by analysis of the sample drawn from the cham-

[1] If for convenience it be necessary to terminate an experiment at any moment, and a difference still exists between the final and initial temperatures, and between the final and initial pressures, the error so arising, due to the initial volume of the gas of the chamber being thereby increased or diminished, must be taken into consideration in the summing up of the general results.

ber will give the total weight of the carbon dioxide produced by the animal. It is evident if during the experiment, oxygen has only been consumed and carbon dioxide only produced, the latter being as rapidly absorbed as produced, that the composition of the gas of the chamber will be the same at the end as at the beginning of the experiment. That the gas of the chamber during the experiment does not differ to any great extent from that of the atmosphere is shown not only by the analysis of the air but from the fact that the animals do not experience any discomfort even after a much longer sojourn in the chamber than that to which they were subjected in the experiments by the authors. It should be added in this connection that the air of the chamber is neither altered by the food nor excreta of the animal. Let us consider now the data at our disposal by means of which the composition of the air of the chamber at the beginning and end of the experiment can be determined. The volume of air at the beginning of the experiment is equal to that which is contained in the chamber, in the pipettes for the absorbing of the carbon dioxide, and in the connecting tubes less the volume of air displaced by the animal and food which are introduced into the the chamber. The determination of both the latter volumes when the density of the food can not be determined, can only be made approximately but in taking it as equal to the volume of air displaced by an equal weight of water the error committed can be but slight. This is equally true at the end of the experiment, for apart from the oxygen consumed and carbon dioxide produced and nitrogen present being in relatively large quantities it must be remembered that by far the greatest part of the food consumed is still present either within the animal or in its excreta. Indeed the only part of the food actually disappearing and which diminishes its volume is that entering into the formation of the carbon dioxide and which must in any case occupy less volume than the water having the same weight as the carbon dioxide produced. Let V represent the volume in litres of the air of the chamber on the supposition that the animal has just been enclosed within the latter, H the elastic force of that air, at its temperature, f the pressure of the aqueous vapor at that temperature to be deducted from H, it acting in opposition to it, then the weight of the oxygen and nitrogen that the chamber contains at the beginning of the experiment can be determined by substituting in the following equations

$$\text{Weight of oxygen}=0{\cdot}2095.\ 1^{gr.},4298.\ V.\ \frac{1}{1+0{\cdot}00367.t}.\ \frac{H-f}{760}$$

$$\text{Weight of nitrogen}=0{\cdot}7905.\ 1^{gr.},2562.\ V.\ \frac{1}{1+0{\cdot}00367.t}.\ \frac{H-f}{760}$$

the values of V, H, t and f obtained by observation; 0·2095 and 0·7905 representing the amounts of oxygen and nitrogen per volume in 100 volumes of air and $1^{\cdot gr.}4298$ and $1^{\cdot gr.}2562$ the weight of a litre of oxygen and nitrogen respectively at standard pressure and temperature. At the end of the experiment H, t and f being made the same as at the beginning, the total volume of air then within the chamber will be unchanged its composition having been modified by the amount of carbon dioxide or other gases produced and remaining in the chamber. The weight of carbon dioxide oxygen and nitrogen or other gases present in the chamber at the end of the experiment is then determined by multiplying the weight of the gases obtained from the sample of gas drawn from the chamber by the ratio of the volume of air of the chamber V to that of the sample v. Let us suppose that C, O and N represent the weight of the carbon dioxide oxygen and nitrogen in the sample of air drawn from the chamber and that $\frac{V}{v}=M$; then CM, OM and NM will be the weight of the carbon dioxide, oxygen and nitrogen in the chamber at the end of the experiment. The weight of the carbon dioxide present in the chamber must be added as already mentioned to that obtained from the pipettes to obtain the total amount of carbon dioxide produced while the weight of the oxygen remaining in the chamber must be deducted from the sum of the weight of oxygen present in the chamber at the beginning of the experiment and that delivered to the chamber during the experiment to obtain the total weight of oxygen consumed. Finally the increase or diminution in the weight of the nitrogen within the chamber at the beginning and end of the experiment amounting to perhaps the 0·02 of a gramm the authors regard as being due to errors in the eudiometrical readings rather than as nitrogen exhaled or inhaled by the animal, the amount of nitrogen in the chamber present being the same at the end as at the beginning of the experiments.

Method of Determining the Weight of the Carbon Dioxide Absorbed by the Solution of Soda in the Pipettes.

The method made use of by the authors in determining the weight of the carbon dioxide absorbed by the soda solution in the pipettes was essentially that recommended by Regnault. It depends upon the decomposition of the sodium carbonate in the solution through the addition of sulphuric acid and the reabsorbing of the carbon dioxide so set free by passing the latter through bulbs, etc. containing soda, the increase in the weight of the bulbs giving the weight of the carbon dioxide absorbed. The apparatus represented in F Plate II consists of a litre flask B into which is poured a sample of the soda solution from the pipettes to be analyzed. Through the cork closing the flask pass three tubes, the first tube communicates with the U shaped tube A containing soda and pumice stone for the absorption of the carbon dioxide in the air that passes through the apparatus at the end of the experiment. The second tube serves for the introduction of the sulphuric acid which should be a little less dense than the alkaline solution and added gradually to the latter, the mixture being slowly heated by gas jets to boiling. The third tube communicates with the narrow flask C containing concentrated sulphuric acid, the latter communicating in turn with the tube D containing pumice stone and sulphuric acid for drying the air and through which the carbon dioxide developed passes on its way to the Liebig bulbs E containing a concentrated solution of soda and the tube F containing pumice stone and small pieces of caustic soda. The remaining tubes G and H contain pumice stone and concentrated sulphuric acid. The increase in weight of the three tubes E F and G at the end of the experiment, the tubes having been previously weighed at the beginning, gives the weight of the carbon dioxide absorbed. To ensure accuracy in the weighing of the tubes E, F, G three similar tubes disposed in the same manner and displacing an equal volume of air should be used as counter weights.

The tube H containing pumice stone and sulphuric acid serves to prevent the moist air depositing water in the tube G. Finally by means of the aspirating jar I a current of air is made to pass through the apparatus and of so carrying the last traces of carbon dioxide to the soda solution absorbing it. In order to maintain the tubes firmly bound together and to facilitate their connection and disconnection they are all clamped to a solid wooden framework by means of which they can all be removed together and in position when desirable. The weight of the carbon dioxide previously existing in the soda solution placed in the pipettes at the beginning of the experiment for absorption of the carbon dioxide produced by the animal is determined by means of the same apparatus and must of course be deducted from the weight of the carbon dioxide absorbed, present in the soda solution at the end of the experiment.

It has already been mentioned, that by means of the accessory tube T Pl. I given off by the tube leading from the chamber, to the carbon dioxide pipette R, that a sample of gas can be drawn into the large mercurial manometer. By so turning its three-way stop cock, as to let the mercury flow out, the sample so obtained is afterwards driven over to the absorbing or explosion apparatus for analysis. This is accomplished by pouring mercury into the limb of the manometer opposite that containing the sample, the three-way stop cock being so turned as to put both limbs in communication and then of retransferring to the manometer for determination of volume of gases absorbed. The method made use of by the authors, however, in order to expedite the analysis is to draw the sample of gas from the chamber directly into a Hempel graduated burette B[1] filled with mercury, the latter, Plate III, Fig. 1, flowing out of the burette as the mercurial reservoir A with which the burette communicates is lowered by means of the wheel work C attached to the solid wooden frame fastened to the table. The sample of gas so obtained reduced to standard temperature and pressure is then driven out of the burette B by elevating the mercurial reservoir into a Hempel pipettte F containing a concentrated solution of soda and after remaining there long enough for the absorption of any carbon dioxide present is driven back into the graduated burette by lowering the mercurial reservoir, the diminution in volume, the latter reduced to standard temperature and pressure, representing the carbon dioxide absorbed. The pipette for the absorption of the carbon dioxide being removed, the burette is connected with one containing pyrogallic acid into which the sample of gas just freed of its carbon dioxide is driven by elevating the reservoir and in which it is allowed to remain until the oxygen present is absorbed. The sample of gas being then driven back into the graduated burette by lowering the reservoir the diminution in volume, reduced to standard temperature and pressure, represents the volume of oxygen absorbed. The volume of gas now remaining in the burette the authors regarded as consisting of nitrogen. At least the volume of residual gas in the burette was

[1] Neue Methoden für Analyse der Gase, von Dr. W. Hempel, Braunschweig, 1880.

usually such as it ought to be on the supposition that it was nitrogen, and as can be shown experimentally by transferring the gas to the Explosion Apparatus Plate III, Fig. 2. The connection with the burette containing the gas is made with that limb of the apparatus A which has been previously filled with a solution of soda the latter being forced up by the mouth applied at the end of the other limb F and the latter then clamped. A known volume of oxygen being then introduced, and a sufficient volume of detonating gas developed electrolytically by means of three Daniell cells connected with the platinum plates, through the binding screws H H the gaseous mixture is exploded by connecting a Ruhmkorff apparatus with the platinum terminals G G. The fact of there being no diminution in the volume of the residual air as ascertained by transferring the gas back to the graduated burette proves the absence of at least hydrogen, heavy carburetted hydrogen, $C_2 H_4$ and light carburetted hydrogen or marsh gas, $C H_4$ the gases which are the most likely to be present, the two former coming from the rectum of the animal the latter from its food. That there is no free hydrogen[1] is further shown in the absence of absorption on passing the residual gas through palladium. The following tabulated actual experiment will serve to illustrate the general method and order of experimentation.

Experiment No. 17.
Oct. 29*th*, 8.45 *P. M.*
2 Pigeons.

BEGINNING OF EXPERIMENT.

Weight of animal	$0^{\cdot kil.}567$
" " food	$0^{\cdot kil.}000$
Barometer	$748^{mm.}$
Temp. of Chamber	18°C
Pressure of Aq. Vap.	15°·35

Vol. of Gas of Chamber at standard temp. and pressure $= 47{\cdot}6\text{ lit.} - 0{\cdot}567 . \dfrac{748-15{\cdot}35}{760\,(1+00367{\cdot}18)} = 42{\cdot}53\text{ lit.}$

[1] Were these gases present in the residual air then after explosion with oxygen water and carbon dioxide would be formed and retained in the pipette the volume of the gas being consequently diminished. It should be mentioned, however, in this connection that it is extremely difficult whatever the kind of apparatus used, to determine such very small volumes of hydrogen or carburetted hydrogen or marsh gas as are likely to be present in the sample of gas drawn from the chamber for analysis and in neglecting to take these gases into account no very sensible error, at least in most instances, will be introduced into the result.

		GRAMMES.
Weight of Oxygen in Chamber.	= 0·2095 1·4298 gr. 42·53	= 12·739
Weight of Nitrogen in Chamber	= 0·7905 1·2562 gr. 42·53	= 42·220
Temp. of Oxygen in Pipette		19°
Pressure of Aq. Vap. aband. by Calcium Chloride sol. .		7·mm·679

GRAMMES.

Weight of Oxygen in Pipette. $= 1{\cdot}4298 \text{ gr. } 19{\cdot}440 \dfrac{748-7{\cdot}67}{760\ (1+00367{\cdot}19)} = 25{\cdot}297$

Weight of Pipettes and Soda sol.	= 7683·000
" "	= 6238·000
" Soda sol. or difference	= 1445·000
Sample of Soda sol. analyzed = 140· cc	
Weight of tubes at end	= 258·35
" " beginning	= 257·50
Carbon dioxide absorbed or difference	= 000·85
Carbon dioxide in Soda sol. used	= 8·77

End of Experiment.

Duration of experiment	21 hours.
Weight of animal	= 0·529
" excreta	= 0·038
	MM.
Barometer	758
Pressure in gauge	10
Elastic force of gas in chamber	748
Temperature of chamber	18°C

Vol. of gas of chamber at standard temp. and press. = 42·53 LIT.

Analysis of Sample Gas.

Barometer	762·mm·6
Temperature of laboratory	18°5

Pressure of aq. vapor		$15^{\cdot mm}\cdot 8$
Vol. of sample of gas at observed temp. and press.	=	71 cc
Vol. of sample reduced to stand. temp. and press. before absorption of carbon dioxide.	=	65·32 cc
Vol. of sample after absorption of carbon dioxide.	=	64·40 cc
Carbon dioxide absorbed.	=	00·92 cc
Vol. of sample after absorption of Oxygen.	=	51·71 cc
Oxygen absorbed.	=	12·69 cc

COMPOSITION OF GAS OF CHAMBER.

$$\frac{\text{Volume of Gas of chamber.}}{\text{Volume of Gas of sample.}} = \frac{42530}{65\cdot32} = 651$$

	LIT.	GRAMMES.		
0·92 651 =	0·6 1·966 =	1·179	= Carbon dioxide.	In chamber.
12·69 651 =	8·2 1·429 =	11·789	= Oxygen.	
51·71 651 =	33·6 1·256 =	42·238	= Nitrogen.	

	Composition per volume.	Composition per cent.
Carbon dioxide.	0·60	1·4
Oxygen.	8·25	19·5
Nitrogen.	33·62	79·1
	42·47	100·0

		GRAMMES.
Weight of Oxygen delivered to chamber from Pipette	=	25·297
" " in chamber at beginning of exp.	=	12·739
" " available	=	38·036
" " in chamber at end of exp.	=	11·789
" " consumed by animal	=	26·247
" " " " " per hour	=	1·249
" " " " " " " per kilo.	=	2·202
" Pipettes and Soda sol.	=	7712·000
" "	=	6238·000
" Soda sol. or difference	=	1474·000

Weight of sample of Soda sol. analyzed 140 cc		
" Tubes at end	=	257·72
" " at beginning	=	254·20
Carbon dioxide absorbed or difference	=	003·50
1474 gr. of Soda sol. at end contained Carbon dioxide	=	37·060
1445 " " at beg. " "	=	8·770
Carbon dioxide produced by animal	=	28·280
" " absorbed by Soda sol. rem. in chamber	=	1·179
Total CO_2 produced by animal	=	29·459
Weight of Oxygen in Carbon dioxide produced	=	21·424

$$\frac{\text{Weight of Oxygen in Carbon dioxide produced}}{\text{Weight of Oxygen consumed}} = \text{Resp. Quot.} = \frac{21{\cdot}424}{26{\cdot}247} = 0{\cdot}816$$

Weight of Nitrogen in chamber at beginning	=	42·22
" " " at end	=	42·20
		00·02
W. of CO_2 produced by animal per hour	=	1·402
W. of CO_2 produced per hour per kil. of animal	=	2·472

In order to test the accuracy of the method of experimentation just described by control experiments the authors burned within the chamber a given weight of stearic acid. $6^{gr}{\cdot}7$ of stearic acid ($C_{18} H_{36} O_2$) when burned should theoretically produce 18·9 gr. CO_2. When burned in the chamber of the respiratory apparatus, that amount of stearic acid actually produced 18·5 gr. of CO_2. The loss $0^{gr}{\cdot}4$ CO_2 or 2·1. pc. was not, therefore, greater than what might been have anticipated.

The animals experimented with, rabbits, monkeys, pigeons, turtles, enjoying good health at the beginning of the experiment, did not appear to suffer in any way from their sojourn in the chamber of the respiratory apparatus. The food placed in the chamber when the animals had not been previously fed was in some instances not eaten, the animal apparently not being then hungry. The period of experimentation extended through the winter, spring and summer months of 1890. The hour of experiment selected, day or night, depended upon the convenience and the amount of time at the disposal of the experimenters.

Experiment No. 1.
Jan. 15*th.*
RABBIT.

Weight of animal	2·kil·5
Weight of food	0·kil·0
Duration of experiment	7 hours, day.
Difference between the initial and final temperature of the gas of the chamber	+0°·5 C.
Difference between the initial and final pressure of the gas of the chamber	1·mm·5

Composition of gas of chamber at the end of the experiment		Composition per cent	
Carbon dioxide	0·807	Carbon dioxide	2·00
Oxygen	7·331	Oxygen	18·00
Nitrogen	33·737	Nitrogen	80·00
	41·875		100·00

	GRAMMES.
Weight of oxygen consumed	15·994
Weight of carbon dioxide produced . . .	19·762
Weight of oxygen contained in the carbon dioxide	14·372
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·898
Weight of oxygen consumed per hour . .	2·284
Weight of oxygen consumed per hour per kilogramme of animal	0·913
Weight of carbon dioxide produced per hour .	2·823
Weight of carbon dioxide produced per hour per kilogramme of animal	1·129

Experiment No. 2.
Jan. 20*th.*
RABBIT.

Weight of animal	2.kil·4
Weight of food, turnips	0.kil·4
Duration of experiment	12 hrs. 45 min. night.
Difference between the initial and final temperature of the gas of the chamber . . .	+0°·5
Difference between the final and initial pressure of the gas of the chamber	+6mm.

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	0·649	Carbon dioxide	1·6
Oxygen	7·755	Oxygen	19·0
Nitrogen	32·333	Nitrogen	79·4
	40·737		100·0

	GRAMMES.
Weight of oxygen consumed	31·53
Weight of carbon dioxide produced . . .	35·26
Weight of oxygen contained in the carbon dioxide	25·65
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·81
Weight of oxygen consumed per hour . . .	2·48
Weight of oxygen consumed per hour per kilogramme of animal	1·03
Weight of carbon dioxide produced per hour .	2·76
Weight of carbon dioxide produced per hour per kilogramme of animal	1·15

Experiment No. 3.

Jan. 24*th.*

RABBIT.

Weight of animal	2.kil.3
Weight of food	0.kil.0
Duration of experiment	7·5 hrs., day.
Difference between the initial and final temperature of the gas of the chamber	0°·5 C.
Difference between the initial and final pressure of the gas of the chamber	+10mm.

Composition of gas of chamber at the end of the experiment		Composition per cent	
Carbon dioxide	0·448	Carbon dioxide	1·00
Oxygen	8·655	Oxygen	20·10
Nitrogen	34·036	Nitrogen	78·90
	43·139		100·00

	GRAMMES.
Weight of oxygen consumed	9·219
Weight of carbon dioxide produced . . .	10·706
Weight of oxygen contained in the carbon dioxide	7·786

Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·844
Weight of oxygen consumed per hour . . .	1·229
Weight of oxygen consumed per hour per kilogramme of animal	0·534
Weight of carbon dioxide produced per hour .	1·427
Weight of carbon dioxide produced per hour per per kilogramme of animal	0·620

Experiment No. 4.

Feb. 3rd.

RABBIT.

Weight of animal	2·kil·6
Weight of food	0·kil·
Duration of experiment	7·5 hrs., day.
Difference between the initial and final temperature of the gas of the chamber . . .	+2°C.
Difference between the initial and final pressure of the gas of the chamber	1·mm·8

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	0·983	Carbon dioxide	2·3
Oxygen	7·244	Oxygen	17·3
Nitrogen	33·787	Nitrogen	80·04
	42·014		100·00

	GRAMMES.
Weight of oxygen consumed	15·00
Weight of carbon dioxide produced . . .	19·80
Weight of oxygen contained in the carbon dioxide	14·40
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·96
Weight of oxygen consumed per hour . . .	2·00
Weight of oxygen consumed per hour per kilogramme of animal	0·70
Weight of carbon dioxide produced per hour .	2·64
Weight of carbon dioxide produced per hour per kilogramme of animal	1·01

Experiment No. 5.

Feb. 5th.

RABBIT.

Weight of animal	$2^{\cdot kil.}3$
Weight of food, turnips	$0^{\cdot kil.}2$
Duration of experiment	11 hours, day.
Difference between the initial and final temperature of the gas of the chamber . . .	+1° C.
Difference between the initial and final pressure of the gas of the chamber	$+4^{\cdot mm.}4$

Composition of gas of chamber at the end of the experiment		Composition per cent	
Carbon dioxide	0·886	Carbon dioxide	2·1
Oxygen	7·763	Oxygen	18·7
Nitrogen	32·853	Nitrogen	79·2
	41·502		100·0

	GRAMMES.
Weight of oxygen consumed	22·534
Weight of carbon dioxide produced . . .	28·132
Weight of oxygen contained in the carbon dioxide	20·459
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·907
Weight of oxygen consumed per hour . . .	2·048
Weight of oxygen consumed per hour per kilogramme of animal	0·890
Weight of carbon dioxide produced per hour .	2·557
Weight of carbon dioxide produced per hour per kilogramme of animal	1·111

Experiment No. 6.

Feb. 7th.

RABBIT.

Weight of animal	$2^{\cdot kil.}5$
Weight of food	$0^{\cdot kil.}0$
Duration of experiment	9 hrs.
Difference between the initial and final temperature of the chamber	+1°C.
Difference between the initial and final pressure of the gas of the chamber	$+8^{mm.}$

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	0·919	Carbon dioxide	2·15
Oxygen	7·849	Oxygen	18·37
Nitrogen	33·963	Nitrogen	79·48
	42·731 Lit.		100·00

	GRAMMES.
Weight of oxygen consumed	18·526
Weight of carbon dioxide produced . . .	24·010
Weight of oxygen contained in the carbon dioxide	17·470
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·957
Weight of oxygen consumed per hour . . .	2·058
Weight of oxygen consumed per hour per kilogramme of animal	0·823
Weight of carbon dioxide produced per hour . .	2·668
Weight of carbon dioxide produced per hour per kilogramme of animal	1·067

Experiment No. 7.

Feb. 10*th.*

RABBIT.

Weight of animal	$2^{\text{kil.}}2$
Weight of food, turnips	$0^{\text{kil.}}2$
Duration of experiment	11 hours, night.
Difference between the initial and final temperature of the gas of the chamber . . .	0° C.
Difference between the initial and final pressure of the gas of the chamber	$+5^{\text{mm.}}$

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	0·823	Carbon dioxide	2·00
Oxygen	7·279	Oxygen	17·00
Nitrogen	34·956	Nitrogen	81·00
	43·058		100·00

	GRAMMES.
Weight of oxygen consumed	20·53
Weight of carbon dioxide produced . . .	24·60

Weight of oxygen contained in the carbon dioxide	17·90
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·87
Weight of oxygen consumed per hour . . .	1·86
Weight of oxygen consumed per hour per kilogramme of animal	0·84
Weight of carbon dioxide produced per hour . .	2·23
Weight of carbon dioxide produced per hour per kilogramme of animal	1·01

Experiment No. 8.

Feb. 14*th.*

RABBIT.

Weight of animal	2·kil·5
Weight of food, fed before experiment . . .	
Duration of experiment	1·15 hrs., night.
Difference between the initial and final temperature of the gas of the chamber . . .	0° C.
Difference between the initial and final pressure of the gas in the chamber	+11mm.

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	0·889	Carbon dioxide	2·00
Oxygen	7·946	Oxygen	19·00
Nitrogen	32·911	Nitrogen	79·00
	41·646		100·00

	GRAMMES.
Weight of oxygen consumed	21·58
Weight of carbon dioxide produced . . .	26·75
Weight of oxygen contained in the carbon dioxide	19·45
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·90
Weight of oxygen consumed per hour . . .	1·86
Weight of oxygen consumed per hour per kilogramme of animal	0·74
Weight of carbon dioxide produced per hour . .	2·32
Weight of carbon dioxide produced per hour per kilogramme of animal	0·92

Experiment No. 9.
Feb. 18*th.*
RABBIT.

Weight of animal	2·kil·1
Weight of food, turnips	0·kil·4
Duration of experiment	12 hrs., night.
Difference between the initial and final temperature of the gas of the chamber . . .	+4° C.
Difference between the initial and final pressure of the gas of the chamber	0·m·0

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	1·230	Carbon dioxide	3·000
Oxygen	6·033	Oxygen	14·000
Nitrogen	34·165	Nitrogen	83·000
	41·428		100·000

	GRAMMES.
Weight of oxygen consumed	24·396
Weight of carbon dioxide produced . . .	29·310
Weight of oxygen contained in the carbon dioxide	21·316
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·873
Weight of oxygen consumed per hour . . .	2·033
Weight of oxygen consumed per hour per kilogramme of animal	0·968
Weight of carbon dioxide produced per hour . .	2·442
Weight of carbon dioxide produced per hour per kilogramme of animal	1·162

Experiment No. 10.
March 11*th.*
RABBIT.

Weight of animal	2·kil·1
Weight of food, turnips	0·kil·4
Duration of experiment	13 hrs., night.
Difference between the initial and final temperature of the gas of the chamber . . .	+1° C.
Difference between the initial and final pressure of the gas of the chamber	+1·mm·4

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	0·693	Carbon dioxide	1·6
Oxygen	6·672	Oxygen	15·7
Nitrogen	35·076	Nitrogen	82·7
	42·441		100·0

	GRAMMES.
Weight of oxygen consumed	27·21
Weight of carbon dioxide produced	34·12
Weight of oxygen contained in the carbon dioxide	24·81
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·91
Weight of oxygen consumed per hour	2·09
Weight of oxygen consumed per hour per kilogramme of animal	0·99
Weight of carbon dioxide produced per hour	2·62
Weight of carbon dioxide produced per hour per kilogramme of animal	1·24

Experiment No. 11.

March 20th.

RABBIT.

Weight of animal	$2^{\cdot kil.}4$
Weight of food, turnips	$0^{\cdot kil.}4$
Duration of experiment	13 hrs., night.
Difference between the initial and final temperature of the gas of the chamber	$+0^{\circ}\cdot 5$ C.
Difference between the initial and final pressure of the gas of the chamber	$0^{\cdot mm.}0$

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	0·558	Carbon dioxide	1·40
Oxygen	6·810	Oxygen	17·00
Nitrogen	32·592	Nitrogen	81·60
	39·960		100·00

	GRAMMES.
Weight of oxygen consumed	27·939
Weight of carbon dioxide produced	37·208

Weight of oxygen contained in the carbon dioxide	27·242
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·971
Weight of oxygen consumed per hour . . .	2·141
Weight of oxygen consumed per hour per kilogramme of animal	0·892
Weight of carbon dioxide produced per hour . .	2·862
Weight of carbon dioxide produced per hour per kilogramme of animal	1·192

Experiment No. 12.
April 28th.
RABBIT.

Weight of animal	2·kil·00
Weight of food, turnips	0·kil·12
Duration of experiment	9 hrs. 45 min., day.
Difference between the initial and final temperature of gas in the chamber	+5° C.
Difference between the initial and final pressure of the gas of the chamber	+3·mm·5

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	1·194	Carbon dioxide	2·85
Oxygen	7·688	Oxygen	18·39
Nitrogen	32·927	Nitrogen	78·76
	41·809		100·00

	GRAMMES.
Weight of oxygen consumed	17·535
Weight of carbon dioxide produced . . .	21·878
Weight of oxygen contained in the carbon dioxide	15·911
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·907
Weight of oxygen consumed per hour . . .	1·807
Weight of oxygen consumed per hour per kilogramme of animal	0·903
Weight of carbon dioxide produced per hour . .	2·254
Weight of carbon dioxide produced per hour per kilogramme of animal	1·127

Experiment No. 13.
May 2nd.
RABBIT.

Weight of animal	1·kil·8
Weight of food, turnips	1·kil·13
Duration of experiment	11 hrs. 45 min., night.
Difference between the initial and final temperature of the gas of the chamber . . .	0° C
Difference between the initial and final pressure of the gas of the chamber	—10mm.

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	0·567	Carbon dioxide	1·40
Oxygen	7·479	Oxygen	18·58
Nitrogen	32·228	Nitrogen	80·02
	40·274		100·00

	GRAMMES.
Weight of oxygen consumed	27·228
Weight of carbon dioxide produced . . .	39·332
Weight of oxygen contained in the carbon dioxide	28·605
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	1·050
Weight of oxygen consumed per hour . . .	2·326
Weight of oxygen consumed per hour per kilogramme of animal	1·292
Weight of carbon dioxide produced per hour .	3·361
Weight of carbon dioxide produced per hour per kilogramme of animal	1·867

Experiment No. 14.
April 1st.
MONKEY, CEBUS CAPUCINUS.

Weight of animal	2·kil·00
Weight of food, orange	0·kil·170
Duration of experiment	5 hrs., day.
Difference between the initial and final temperature of the gas of the chamber . . .	+0°·5 C.
Difference between the initial and final pressure of the gas of the chamber	+2mm.

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	0·855	Carbon dioxide	2·10
Oxygen	8·422	Oxygen	19·80
Nitrogen	33·117	Nitrogen	78·10
	42·394		100·00

	GRAMMES.
Weight of oxygen consumed	13·47
Weight of carbon dioxide produced . . .	16·389
Weight of oxygen contained in the carbon dioxide	11·919
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·884
Weight of oxygen consumed per hour . . .	2·694
Weight of oxygen consumed per hour per kilogramme of animal	1·347
Weight of carbon dioxide produced per hour . .	3·277
Weight of carbon dioxide produced per hour per kilogramme of animal	1·638

Experiment No. 15.
April 3rd.
MONKEY, CEBUS CAPUCINUS.

Weight of animal	1·kil·50
Weight of food, sweet potatoes	0·kil·158
Duration of experiment	6 hrs. 20 min., day.
Difference between the initial and final temperature of the gas of the chamber . . .	+3° C.
Difference between the initial and final pressure of the gas of the chamber	+1mm.

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	0·418	Carbon dioxide	0·98
Oxygen	8·759	Oxygen	20·61
Nitrogen	33·324	Nitrogen	78·41
	42·501		100·00

	GRAMMES.
Weight of oxygen consumed	14·31
Weight of carbon dioxide produced . . .	18·73

Weight of oxygen contained in the carbon dioxide	13·62
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·95
Weight of oxygen consumed per hour . . .	2·27
Weight of oxygen consumed per hour per kilogramme of animal	1·51
Weight of carbon dioxide produced per hour . .	2·97
Weight of carbon dioxide produced per hour per kilogramme of animal	1·98

Experiment No. 16.

May 26*th.*

2 Pigeons.

Weight of animals	0·kil·570
Weight of food, corn	0·kil·180
Duration of experiment	13 hrs. 15 min., day.
Difference between the initial and final temperature of the gas of the chamber . . .	+0°·5 C.
Difference between the initial and final pressure of the gas of the chamber	+19·mm·00

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	0·630	Carbon dioxide	1·42
Oxygen	9·447	Oxygen	21·37
Nitrogen	34·131	Nitrogen	77·21
	44·208		100·00

	GRAMMES.
Weight of oxygen consumed	26·6804
Weight of carbon dioxide produced . . .	32·1564
Weight of oxygen contained in the carbon dioxide	23·1592
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·8680
Weight of oxygen consumed per hour . . .	2·0218
Weight of oxygen consumed per hour per kilogramme of animal	3·5470
Weight of carbon dioxide produced per hour . .	2·3471
Weight of carbon dioxide produced per hour per kilogramme of animal	4·1178

Experiment No. 17.
Oct. 29th.
2 PIGEONS.

Weight of animal	0·kil·567
Weight of food	0·kil·0
Duration of experiment	21 hrs.
Difference between the initial and final temperature of the gas of the chamber . . .	0°·0
Difference between the initial and final pressure of the gas of the chamber	0·mm·0

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	0·60	Carbon dioxide	1·4
Oxygen	8·25	Oxygen	19·5
Nitrogen	33·62	Nitrogen	79·1
	42·47		100·0

	GRAMMES.
Weight of oxygen consumed	26·247
Weight of carbon dioxide produced . . .	29·459
Weight of oxygen contained in the carbon dioxide	21·424
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·816
Weight of oxygen consumed per hour . . .	1·249
Weight of oxygen consumed per hour per kilogramme of animal	2·202
Weight of carbon dioxide produced per hour . .	1·402
Weight of carbon dioxide produced per hour per kilogramme of animal	2·472

Experiment No. 18.
April 7th.
TURTLE, PSEUDEMYS MOBILENSIS.

Weight of animal	1·kil·7
Weight of food, sweet potato	0·kil·1
Duration of experiment	96 hours.
Difference between the initial and final temperature of the gas of the chamber . . .	0·° C.
Difference between the initial and final pressure of the gas of the chamber	+19·mm·00

Composition of gas of chamber at the end of the experiment:		Composition per cent:	
Carbon dioxide	0·366	Carbon dioxide	0·85
Oxygen	9·623	Oxygen	22·41
Nitrogen	32·954	Nitrogen	76·74
	42·943		100·00

	GRAMMES.
Weight of oxygen consumed	8·612
Weight of carbon dioxide produced . . .	11·341
Weight of oxygen contained in the carbon dioxide	8·248
Ratio between the weight of the oxygen contained in the carbon dioxide produced, and the weight of the oxygen consumed	0·957
Weight of oxygen consumed per hour . . .	0·088
Weight of oxygen consumed per hour per kilogramme of animal	0·051
Weight of carbon dioxide produced per hour .	0·118
Weight of carbon dioxide produced per hour per kilogramme of animal	0·063

Resume of 13 Experiments as regards the Consumption of Oxygen and Production of Carbon Dioxide by Rabbits.

Exp.	O, consumed per hour. GRAMMES.	O, consumed per hour per kil. of animal. GRAMMES.	CO_2, produced per hour. GRAMMES.	CO_2, produced per hour per kil. of animal. GRAMMES.	Resp. Quot
No. 1.	2·28	0·91	2·82	1·12	0·89
" 2.	2·48	1·03	2·76	1·15	0·81
" 3.	1·22	0·53	1·42	0·62	0·84
" 4.	2·00	0·70	2·64	1·01	0·96
" 5.	2·04	0·89	2·55	1·11	0·90
" 6.	2·05	0·82	2·66	1·06	0·95
" 7.	1·86	0·84	2·33	1·01	0·87
" 8.	1·86	0·74	2·32	0·92	0·90
" 9.	2·03	0·96	2·44	1·16	0·87
" 10.	2·09	0·99	2·62	1·24	0·91
" 11.	2·14	0·89	2·86	1·19	0·97
" 12.	1·80	0·90	2·25	1·12	0·90
" 13.	2·32	1·29	3·36	1·86	1·05
Total,	26·17	11·49	33·03	14·57	11·82

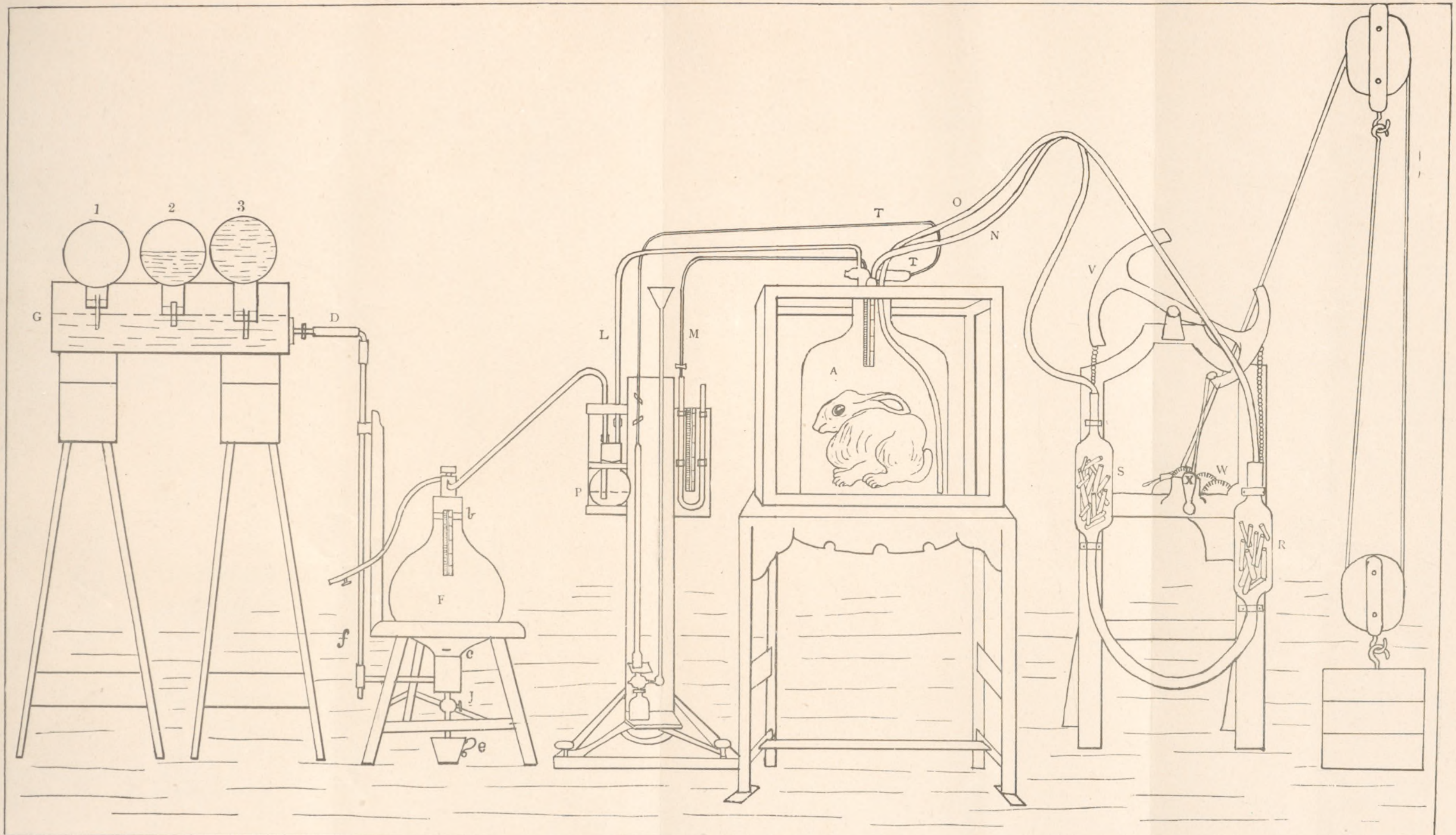
$$\text{Average} = \frac{26{\cdot}17}{13} = 2^{\cdot gr \cdot}01 \quad \frac{11{\cdot}49}{13} = 0^{\cdot gr \cdot}88 \quad \frac{33{\cdot}03}{13} = 2^{\cdot gr \cdot}53$$

$$\frac{14{\cdot}57}{13} = 1^{\cdot gr \cdot}12 \quad \frac{11{\cdot}82}{13} = 0{\cdot}90$$

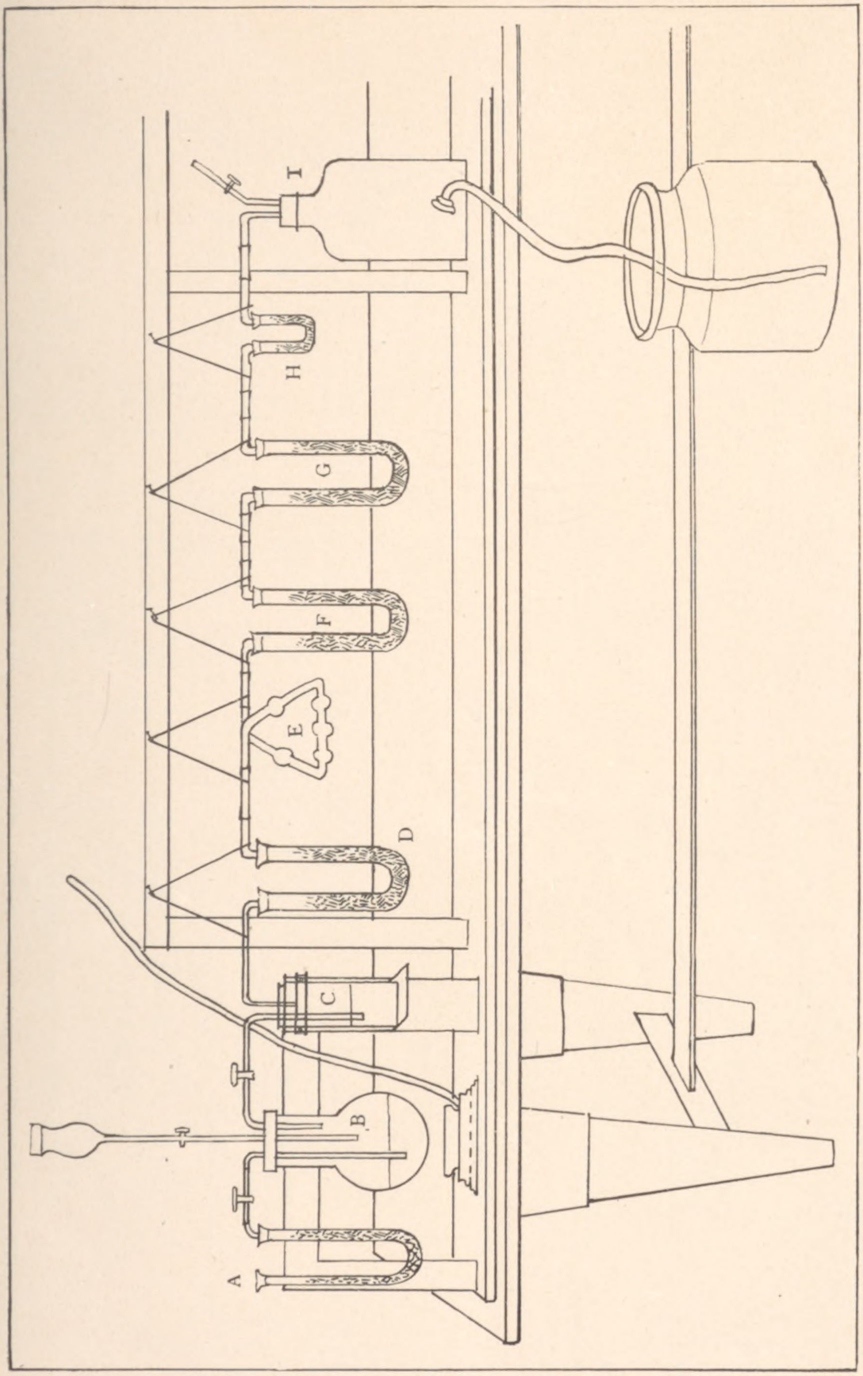
It will be observed from the above resumé that the rabbit consumes upon the average $2^{\cdot gr \cdot}01$ of oxygen per hour and $0^{\cdot gr \cdot}8$ of oxygen per hour per kilogramme of body weight and produces $2^{\cdot gr \cdot}5$ of carbon dioxide per hour and $1^{\cdot gr \cdot}1$ of carbon dioxide per hour per kilogramme of body weight, the respiration quotient or the ratio between the weight of the oxygen contained in the carbon dioxide produced and the weight of the oxygen consumed amounting on the average to 0·9. In this connection it may be mentioned that the rabbit consumes on the average the same amount of oxygen and produces the same amount of carbon dioxide whether the gas breathed, be the atmosphere as under ordinary circumstances, or pure oxygen as in the case of the animal being placed within the chamber of the respiratory apparatus. As the respiratory process in man does not differ from that of the rabbit, at least in its chemical aspects, there is no reason to suppose that any more oxygen would be consumed by man if breathed alone than when breathed as mixed with nitrogen as obtains in the breathing of ordinary air. Notwithstanding that the experiments with the rabbits were performed at different seasons of the year, at different hours of the day or night, that food was or was not eaten, that in some instances the animals were more lively and active than in others, in a word, that the conditions in general varied considerably, nevertheless, it will be seen that the respiratory quotient varied but little in the different experiments.

It may be mentioned that the respiratory quotient as given by Regnault & Reiset, Rauber, Colosanti, Richet, Regnard and others differs but little from that obtained by the authors. Attention is also called to the fact of the consumption of oxygen and production of carbon dioxide being increased by the taking of food—example 6 as compared with example 12 offers the only exception. The animal in the former case, however, weighed more than in the latter.

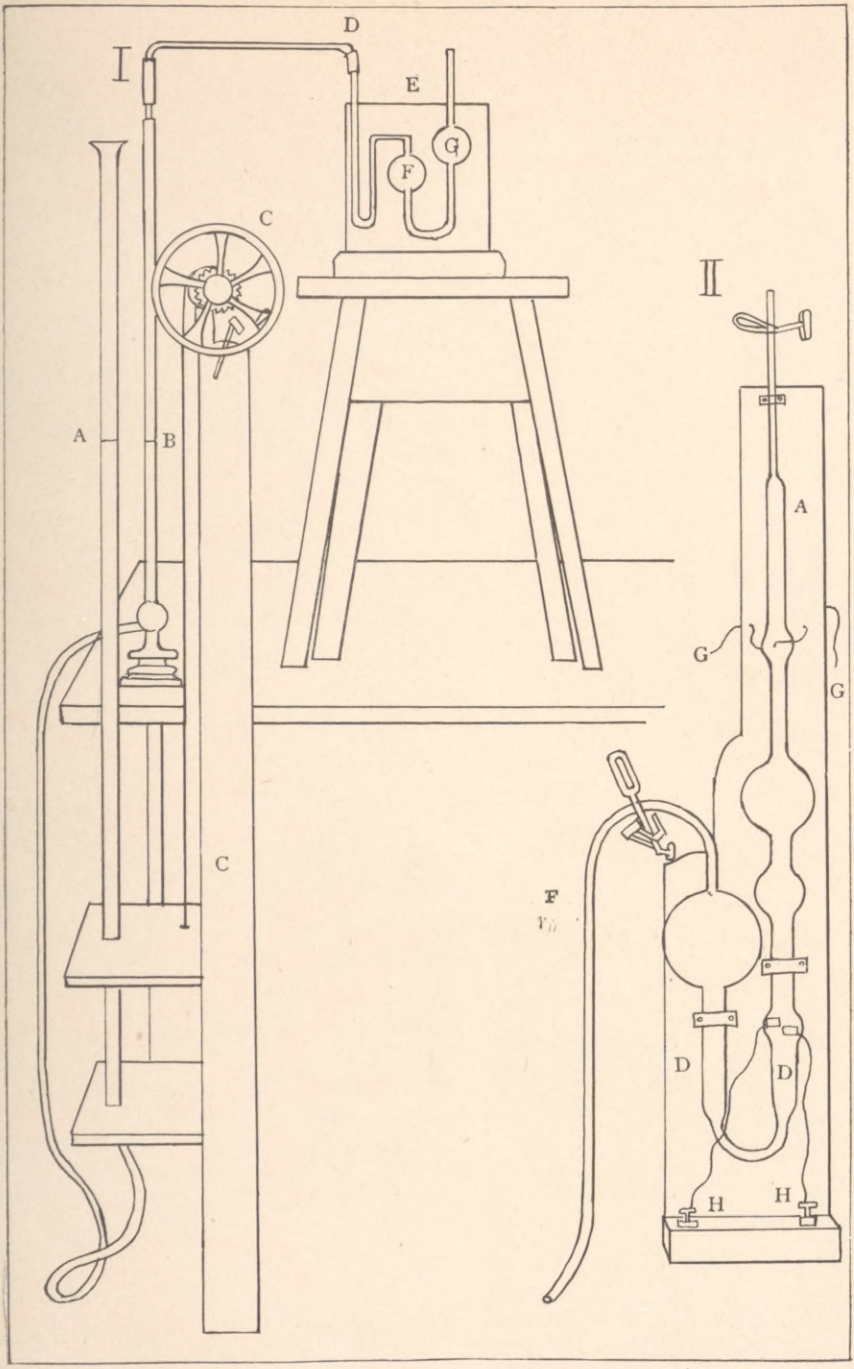
Inasmuch as in their next communication the authors propose to give a detailed account of their observations upon the respiration of monkeys as studied by means of the Voit apparatus, attention is simply called to the fact that the respiratory quotient (Exps. 14, 15) differs but little, if at all, from that of the rabbit. With reference to the experiments with the pigeons (Exps. 16, 17) apart from the fact (of little significance) that one experiment was performed in May and the other in October it should be mentioned that in the first instance the pigeons were fed and were much more active than in the second which accounts for the weight of the oxygen consumed and carbon dioxide produced being so much greater in the former case than in the latter, the respiratory quotient being 0·8. The apparatus made use of by the authors in the investigations just described is not well adapted to the study of respiration as obtained in the lower vertebrata, reptilia, batrachia and invertebrata. Nevertheless, the results of an experiment (Exp. 18) with a turtle (Pseudemys mobilensis) are offered as illustrating how slowly oxygen is consumed and carbon dioxide is produced in such animals, the respiratory quotient, however, being the same as in the mammalia.



CHAPMAN AND BRUBAKER ON RESPIRATION.



CHAPMAN AND BRUBAKER ON RESPIRATION.



CHAPMAN AND BRUBAKER ON RESPIRATION.