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U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS.

REPORT

OF

PRELIMINARY INVESTIGATIONS

ON THE

METABOLISM OF NITROGEN AND CARBON IN THE HUMAN ORGANISM,

WITH

A RESPIRATION CALORIMETER OF SPECIAL CONSTRUCTION.

BY

W. O. ATWATER, Ph. D., C. D. WOODS, B. S., and F. G. BENEDICT, Ph. D.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., June 28, 1897.

SIR: I have the honor to transmit herewith a report of investigations on the metabolism of man, in the conduct of which a respiration calorimeter of special construction was used. The experiments with men herein reported were made in the winter of 1895–96, at Middletown, Conn., under the immediate supervision of Prof. W. O. Atwater, special agent in charge of nutrition investigations. These experiments were, however, only made possible by previous researches with special reference to the development of the apparatus and methods of inquiry.

This work was begun in 1892 under the direction of Professor Atwater in connection with his duties as professor of chemistry in Wesleyan University and director of the Storrs Agricultural Experiment Station. Prof. E. B. Rosa, of Wesleyan University, was associated with the inquiry, on the physical side, from the outset. When investigations on the food and nutrition of man were undertaken by this Department in the fall of 1894, experiments with the respiration calorimeter were made a part of the general plan of work, and it was decided to extend financial aid to these special investigations, which were already well advanced and gave promise of successful issue. Since that time these inquiries have been conducted by the cooperation of this Department, the Storrs Experiment Station, and Wesleyan University. In this way, by the expenditure of comparatively small sums for the promotion of this particular investigation, the Department has been able to secure for publication the results of a large amount of original research in a line of vital importance in connection with the establishment of a scientific basis for the nutrition of man. The work on the respiration calorimeter was far enough advanced by the winter of 1895–96 to justify its use in experiments with men. After several preliminary trials, the data from which were too incomplete to warrant publication, but which were of great service in perfecting arrangements for the succeeding trials, the four experiments reported in this bulletin were made.

While all the details of these experiments are not yet perfectly satisfactory and there is still room for further improvement of the apparatus to be used in such intricate investigations, they nevertheless mark a decided advance over work of similar character hitherto published and give great encouragement to continued researches in this line.

The greatest success thus far has been in the measurement of the metabolism of nitrogen and carbon, and the present report is devoted chiefly to the chemical side of the investigation, which includes these measurements. When these experiments were made the work on the physical side, although carried on with great skill and with highly interesting results, had not given data sufficiently accurate in all their details to make its publication seem advisable. The investigations are proceeding, changes in the apparatus have already resulted in very satisfactory physical measurements, and it is hoped before long to publish more complete data on both the physical and chemical sides of the work.

The general management of these investigations has devolved upon Professor Atwater. In devising and elaborating the apparatus and in the carrying out of that part of the investigation which relates to the measurement of the heat given off from the body and the mechanical work done, Dr. E. B. Rosa, professor of physics of Wesleyan University, has rendered invaluable service. It is expected that in later reports Professor Rosa will appear as joint author in the discussion of the investigations from the physical standpoint. On the chemical side, Dr. Atwater has had the assistance of Prof. C. D. Woods and Dr. F. G. Benedict, joint authors of this report. The skill and ingenuity of the university mechanician, Mr. O. S. Blakeslee, have also contributed in no small degree to the practical embodiment and successful working of the various devices adopted for the perfecting of the apparatus. Other workers whose services deserve special recognition are A. W. Smith, O. F. Tower, A. P. Bryant, and H. M. Burr.

This report is respectfully submitted, with the recommendation that it be published as Bulletin No. 44 of this Office.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

METABOLISM OF NITROGEN AND CARBON IN THE HUMAN ORGANISM.

INTRODUCTION.

In order to ascertain the ways in which food is used in the body and the kinds and amounts which are best suited to people of different classes and under different conditions it is necessary to devise accurate methods of determining the total income and outgo of material and energy in the organism. The importance of such a study of the fundamental principles of nutrition has been recognized for many years, and studies of one or more of the factors of the income and outgo (especially of nitrogen) have received much attention by investigators in this field of science. In experiments of this nature it is customary to express the results as a balance, in which the outgo is subtracted from the income, thus showing the gain or loss.

GENERAL STATEMENT.

So far as the balance of material is concerned, the income consists of food, drink, and oxygen of inhaled air; and the outgo consists of feces, urine, and the products of respiration and perspiration. A complete experiment on the metabolism of material would involve determinations of the total amount of oxygen consumed, the amounts and the elementary and proximate composition of food, feces, urine, and products of respiration and perspiration (including marsh gas from the intestines, and similar products). For the balance of energy, the income would include the potential energy of the food and drink; the outgo would include the potential energy of feces and urine, products of respiration and perspiration, and the kinetic energy given off in heat from the body and the mechanical energy of the external muscular work performed. It is possible that other less familiar forms of energy may be concerned, but these are all which are at present known and which may be measured. Due account must of course be taken of the temperature and specific heats of food, drink, and excretory products, and the heat used or evolved in the condensation of the water of exhalation.

A complete metabolism experiment would involve, therefore, the determination of the following factors of income and outgo of matter and energy:

Factors of income.

Matter: Food, drink, oxygen of air.

Elements of food, drink, and air: N, C, H, O, S, P, Cl, K, Na, Mg, Ca, Fe.

Compounds of food and drink: Water, protein compounds, fats, carbohydrates, and mineral matters.

Energy: Potential energy of (organic) compounds of food and drink.

Factors of outgo.

Matter: Feces, urine, products of respiration and perspiration.
Elements of above: N, C, H, O, S, P, Cl, K, Na, Mg, Ca, Fe.
Compounds: Water of urine and feces; carbohydrates and mineral matter of feces; organic and mineral compounds of urine; CO_2, H_2O, and organic compounds, etc., of products of respiration and perspiration.

Energy: Potential energy of (organic) compounds of feces, urine, and products of respiration and perspiration.
Kinetic energy given off from the body, as heat, external muscular work, and possibly in other forms.

The above statement is, however, incomplete in that it does not take into account the material which the body gains or loses during the experiment and the corresponding energy stored or transformed. This material consists mainly of water, protein compounds, and fats, with smaller amounts of carbohydrates, mineral matters, and other compounds.

The above factors represent the gross income and outgo. The net income would include only the material which the body actually utilizes from food, drink, and air; that is, it represents the income of nutrients, water, and energy consumed minus the unassimilated portion excreted in the feces, taking into account also the incompletely oxidized matter in the urine. The net income of material is that which is taken into the circulation, builds and repairs tissue, and yields energy. The net income of energy is the potential energy of this material plus the energy received with the food and drink in the form of heat.

The gross outgo includes the total material of the excretory products, and the sum of their potential energy and the kinetic energy given off from the body. The net outgo is made up of the excretions of the kidneys, lungs, and skin, and the sum of their potential energy and the kinetic energy given off from the body. The material and the potential energy of the feces are not utilized, but simply rejected.[1]

Metabolism experiments may include the measurement of the income and outgo of one or more of the above factors. When the balance of nitrogen, with or without mineral matter, is determined, the only factors of outgo which enter into account are the urine (sometimes including the perspiration) and feces, since no considerable amount of nitrogen or mineral matter is believed to be excreted in any other form. When the balance of carbon, with or without oxygen and hydrogen, is determined, the products of respiration and perspiration must be taken into account in addition to the urine and feces. Experiments of this nature are commonly called "respiration experiments." The experiments reported here are respiration experiments, devoted especially to the determination of the income and outgo of nitrogen and carbon.

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[1] The residues of digestive juices and other so-called metabolic products of the feces are, it is true, a part of the material which has been digested, absorbed, and metabolized, but they represent material which is neither utilized for building or repairing organs or tissue, nor consumed to yield energy, and which, therefore, may here be classed with the undigested residue of the food.

Investigation regarding the metabolism of matter in animals and man has been very active during the last forty and especially the last twenty years. Indeed the experimental results already obtained in this direction are much more extensive than is commonly supposed. A compilation[1] has recently been prepared by this office which it is believed includes the greater part of the experiments with man and the lower animals in which the balance of income and outgo of one or more chemical elements has been determined. The number of experiments in which the income and outgo of energy has been measured is, however, extremely small.

A review of this work made it evident that research upon nutrition had reached a point where more study of the application of the laws of the conservation of matter and of energy in the living organism was essential. It is not enough to know the kinds and amounts of food consumed as they are shown by dietary studies, or the proportions that are digested as they are learned from digestion experiments, or the general effects of food materials as they are brought out by ordinary feeding trials. Experiments in which the balance of income and outgo of nitrogen are learned by weighings and analyses of food and of the secretions of the kidneys and intestine are extremely useful, but nevertheless inadequate. The balance of income and outgo of the body must be determined both in terms of matter and of energy. For this purpose a respiration apparatus which measured only the income and outgo of matter would not suffice. There was need of an apparatus in which an animal or a man may be placed for a number of hours or days and the amounts and composition of the food and drink and inhaled air, the amounts and composition of the excreta (solid, liquid, and gaseous), the potential energy of the materials taken into the body and given off from it, the quantity of heat radiated from the body, and the mechanical equivalent of the muscular work performed could all be determined.

Respiration apparatus of various sorts have been devised by a number of investigators. They may, perhaps, for convenience, be divided into three classes: (1) Those in which the subject remained in a closed chamber and was supplied with oxygen to take the place of that withdrawn from the air by the processes of respiration. The air in the chamber was analyzed at the beginning and end of the experiment. (2) Those in which the subject remained in a chamber supplied with a current of air which was measured and analyzed as it entered and left the chamber. (3) Those in which the subject did not remain in a chamber, but was provided with apparatus which permitted the measurement and analysis of the inspired and expired air, and the determination of the respiratory quotient. In several instances the last two forms have been combined. Calorimeters have also been devised by many investigators. These have usually been combined with respiration apparatus of some form.

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 45.

An excellent summary of the methods and results of respiration experiments up to about the year 1882, with descriptions of the apparatus employed, has been prepared by Zuntz.[1] About the same time a like excellent account of inquiries regarding the income and outgo of heat of the body was published by Rosenthal.[2] Since that time numerous forms of apparatus have been devised and a large number of experiments have been carried out. Reports of these are published in the various scientific journals and have, so far as known, not yet been summarized.

The apparatus which was used in the present experiments differs in its essential points from that used by other investigators. It consists of a respiration apparatus similar in principle to that of Pettenkofer and Voit,[3] which belongs to the second class mentioned above. In addition there are devices for the measurement of the energy liberated by the organism.

For measuring and analyzing the incoming and outgoing air, new methods have been devised, or the methods already in use have been materially modified. The apparatus for measuring the outgo of energy is entirely original. Therefore, though the apparatus resembles in outward form the respiration apparatus of Pettenkofer and Voit, it differs in so many essential points that it may be fairly termed a new form, and to it the name respiration calorimeter has been applied.

In the earlier experiments referred to above the subject remained in the apparatus for short periods, usually not more than twenty-four hours. In the present experiments the subject remained for several days inside the respiration chamber.

THE EXPERIMENTS REPORTED IN THIS BULLETIN.

The purpose of the present article is to give a description of the apparatus used and of the methods which have been elaborated, together with an account of the experiments thus far made by the authors which bear directly upon the metabolism of matter. Four experiments with men in which the metabolism of nitrogen and carbon has been measured are described. The results obtained regarding the metabolism of hydrogen and energy are to be withheld until some changes which experience has indicated to be desirable in the apparatus and methods can be made, and the results already obtained can be verified and new ones added.

The four experiments, designated by the laboratory numbers 1, 2, 3, and 4, were as follows:

No. 1. An experiment of fifty-four hours with a laboratory assistant.

No. 2. An experiment of fifty-four hours with a laboratory assistant.

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[1] Hermann's Handbuch der Physiologie, vol. 4, pt. 2, pp. 86–162.

[2] Handbuch der Physiologie, vol. 4, pt. 2, pp. 289–456.

[3] Pettenkofer and Voit's apparatus and a number of experiments made with it are described in U. S. Dept. Agr., Office of Experiment Stations Bul. 21, pp. 106–112.

No. 3. An experiment of five days with a chemist.

No. 4. An experiment of twelve days with a physicist.

Several previous experiments, which were less complete, are not reported here.

APPARATUS.

The first requisite for metabolism experiments of the kind here reported is of course reliable methods and apparatus for the accurate determination of the different factors of income and outgo during a given period. This subject received much painstaking thought and care in the present investigation. The fact, however, should be emphasized that although these experiments were carried out with much attention to detail and accuracy, they are regarded simply as preliminary to more elaborate, comprehensive, and exact investigations with improved apparatus.

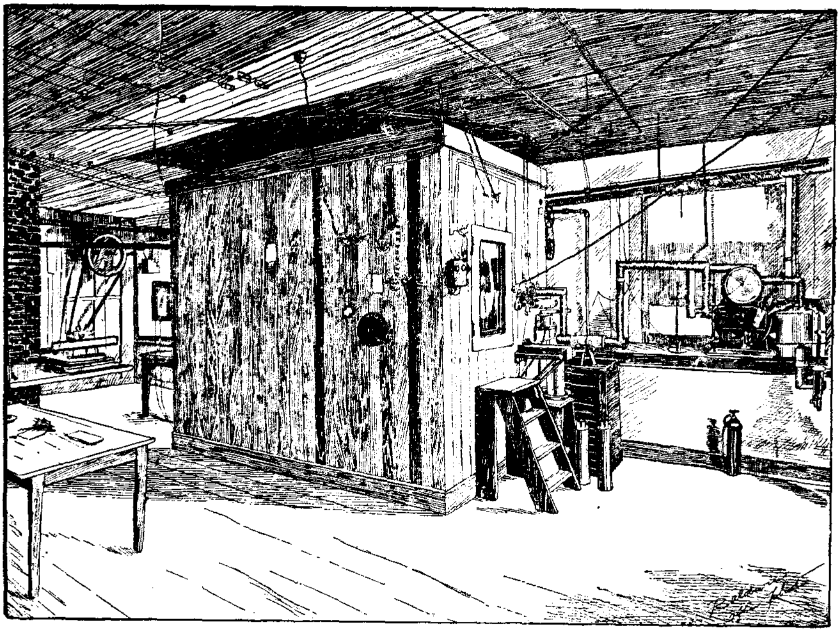

FIG. 1.—Respiration calorimeter.

The apparatus used in the experiments herewith reported consists essentially of a respiration chamber in which the subject stays during the experiment, appliances for maintaining a current of air through the respiration chamber for ventilation, apparatus for measuring and analyzing this ventilating current of air, and appliances for measuring the heat given off from the body (see fig. 1).

The apparatus and methods for the measurement of the heat given off from the body, which were devised by Prof. E. B. Rosa, are believed to be quite novel. The experience gained in the use of these appliances has naturally suggested improvements in the details. The description of this part of the apparatus is reserved for publication after the investigations have further progressed.

The room in which the apparatus is situated and in which the larger part of the work of the experiment is carried on is in the basement of the Orange Judd Hall of Natural Science and is a part of the chemical laboratory of Wesleyan University. It is 35½ feet long, 20 feet wide, and 9 feet high; well ventilated; supplied with gas, water, and electricity, and heated by steam. During the period of the experiments, which was in late winter, the steam heat was insufficient for comfort during part of the night and gas stoves were used in addition. As the building is of sandstone, with very heavy walls, the fluctuations of temperature within, especially in the basement, are comparatively slow. Light is supplied by five large windows, and by gas and electricity. A 1½ kilowatt motor, connected with convenient shafting, furnishes the power.

Opening out of this room is a smaller one, 5 by 11½ feet, fitted with arrangements for cooking the food. It also serves as a dressing room for the subject at the times of entering and leaving the respiration chamber.

THE RESPIRATION CHAMBER.

The respiration chamber is a room or box in which a man may live comfortably during the period of an experiment. The inside dimensions are: Length, 2.15 meters; width, 1.22 meters; height, 1.92 meters. It is provided with conveniences for sitting, sleeping, eating, and working, as well as arrangements for ventilation and for the study of the respiratory products. The chamber consists, in fact, of three concentric boxes, the inner one of metal and the two outer ones of wood.

The inner box, of which the inside dimensions have just been given, is double walled, the inner wall being of sheet copper, the outer of sheet zinc. The two walls are 8 centimeters apart. This double-walled box is held in shape by a wooden framework between the two metal walls. The four vertical corners are rounded, as this simplifies the construction and makes the apparatus rather more convenient for use. The inside volume is approximately 4.8 cubic meters (see figs. 2 and 3).

An opening in the front[1] end of the metal chamber, 70 centimeters high and 49 centimeters wide, serves both the purpose of a window and a door for entrance and exit. Considerable difficulty was experienced in securing an air-tight closure for this door. After numerous unsuccessful experiments with frames of wood and metal and with India-rubber gaskets and other appliances, the simpler plan was adopted of using a large pane of glass in a frame as is done in ordinary windows

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[1] In these descriptions the end in which the window is situated is called the front. The terms right and left are applied to the sides at the right and left of a person standing outside at the front end and facing the window.

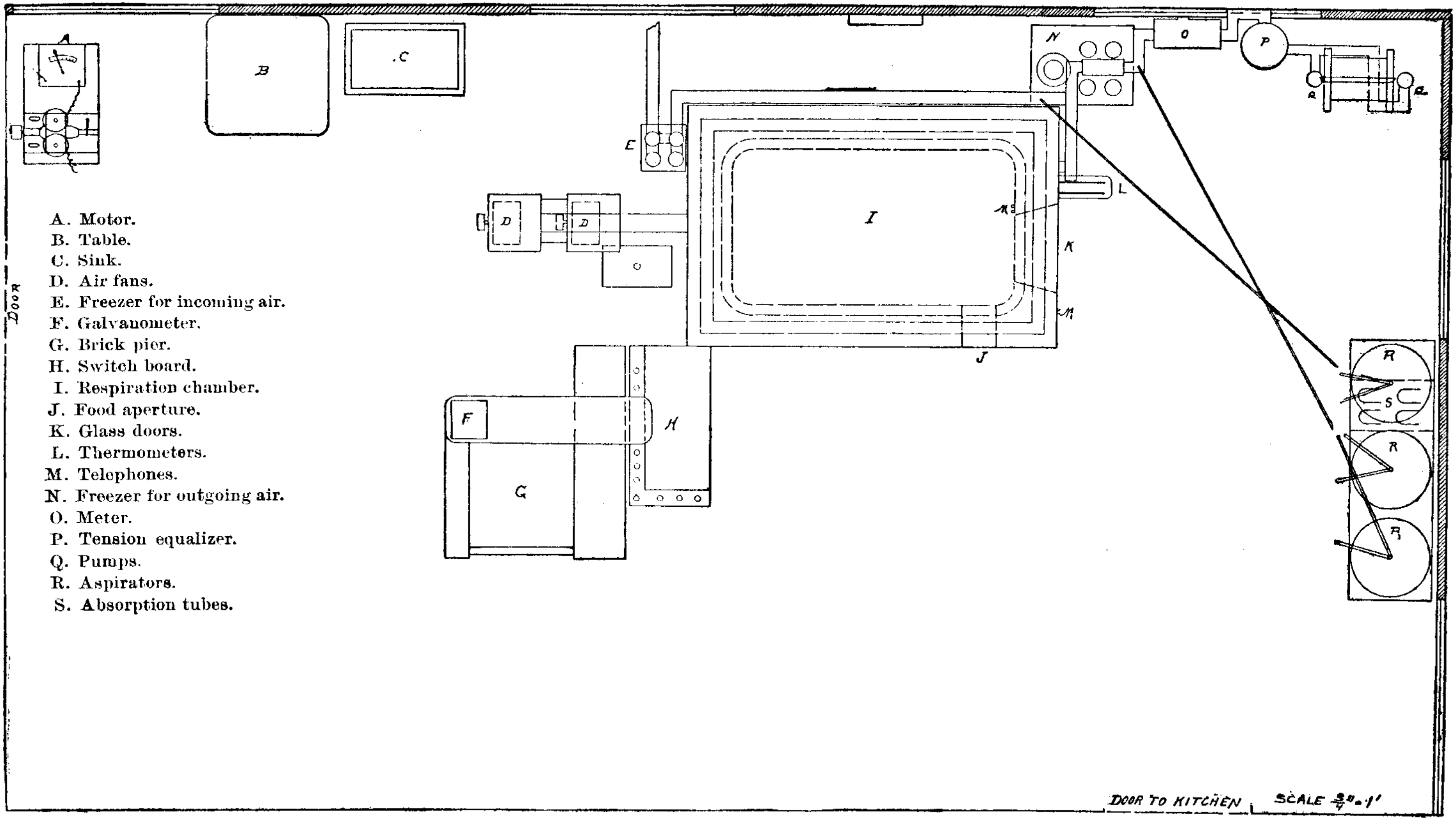

FIG. 2.—Plan of respiration calorimeter room.

and securing it with putty. The labor of putting the glass in at the beginning and taking it out at the end of an experiment is very small, and the plan serves the purpose admirably.

Outside of this double-walled metal box are casings of wood. The outer wooden walls are supplied with glass doors turning on hinges and facing the doors in the metal box.

The purpose of the double metal wall of the inner chamber and of the wooden casings is to facilitate the use of the devices for measurements of heat. The chief use of these latter devices is in connection with the experiments to determine the income and outgo of energy, which are not yet complete for publication.

Numerous passages through the walls are needed for tubes, to convey the ventilating current of air and for a current of water to carry off the heat generated by the body of the occupant of the chamber, wires for various electric connections, metal rods for certain connections between the interior and exterior apparatus, and, finally, the "food tube" for passing the food and drink into the apparatus and taking out the solid and liquid excretory products. The tubes referred to are of various sizes and made of either brass or copper. The "ventilating tubes" have an internal diameter of 4 centimeters. The food aperture is of copper and has an internal diameter of 15 centimeters. It is situated on the left side of the apparatus, and is provided with a cap at each end. The outer cap is attached by a screw so that it may be made air-tight. In putting in the food and other materials the cap is taken off, the receptacle containing the food is placed in the tube and the cap put on again. A signal is then given to the man inside who removes the inner cap and takes out the receptacle. The materials from within are passed out in corresponding manner. In this way there is no danger of ingress or egress of any considerable quantity of air.

A telephone furnishes a means of communication between the inside and outside of the chamber; the wires of the telephone pass through rubber stoppers inserted in a tube, which, in its turn, passes through all of the boxes and walls and is soldered to the inner copper wall. Other wires through the same tube provide for electrical connection with a small bell on the outside so that the person within may call an attendant whenever desired.

Adequate provision is made for the ventilation of the chamber and for maintaining a uniform humidity and temperature by means of the appliances described below (p. 16). An inconvenient rise of temperature is prevented by a current of cold water which passes through a system of pipes inside of the chamber. This device forms a part of the arrangements for measuring the heat given off from the body. As the results of such measurements are not reported in this article, it will suffice to say that the plan followed is in fact the opposite of that used in heating houses by hot water radiators, i. e., instead of passing hot

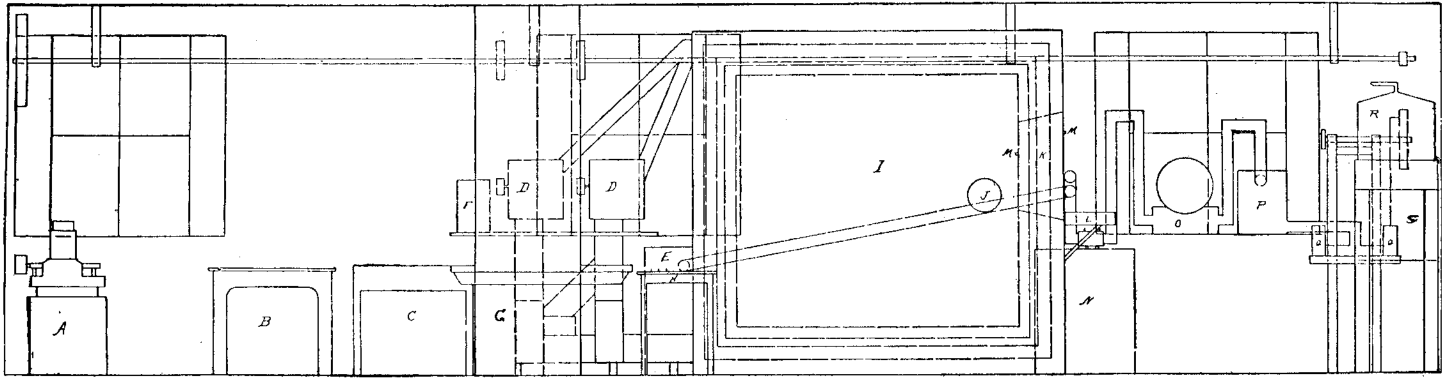

FIG. 3.—Elevation of respiration calorimeter room.

A. Motor.
B. Table.
C. Sink.
D. Air fans.
E. Freezer for incoming air.
F. Galvanometer.
G. Brick pier.
H. Switch board.
I. Respiration chamber.
J. Food aperture.
K. Glass doors.
L. Thermometers.
M. Telephones.
N. Freezer for outgoing air.
O. Meter.
P. Tension equalizer.
Q. Pumps.
R. Aspirators.
S. Absorption tubes.

water through radiators to give off heat for warming the air, cold water is passed through absorbers to remove heat from the air.

A wet and dry bulb hygrometer, capable of being read to tenths of a degree centigrade, is hung in the rear of the chamber and observations were made by the occupant, generally at intervals of two hours, during the period of the experiment. These observations were reported by the telephone and show the hygrometric condition of the air inside of the apparatus.

The furniture used in the experiments consisted of a light folding canvas cot bed, a folding chair, and a folding table. Such clothing and bedding as were needed for comfort were taken in by the man at the beginning of the experiment, and small articles were passed in and out through the food tube at convenient times. The floor was protected by carpeting. The amounts of water held by the furniture and clothing, etc., were determined as accurately as practicable by weighings at the beginning and end of each experiment.

The arrangements for measuring and sampling the air are described as they were actually used in the experiments. They have since been replaced by others which will be described with accounts of experiments now in progress.

APPLIANCES FOR VENTILATION AND FOR THE MEASUREMENT AND ANALYSIS OF THE VENTILATING CURRENT OF AIR.

A satisfactory respiration experiment involves the maintenance of a proper current of air, the accurate measurement of its volume, and the determination of the respiratory products. When a living subject is in the respiration chamber and breathes its air it is essential that the ventilation be sufficient for his comfort, but it is important that the amount passed through the chamber be not too large, on account of the difficulty of accurate measurement and analysis. With a small current the reasonably accurate measurement of the volume is easier than with a large one, smaller samples are needed for analysis, and the samples can be taken and the analyses made more accurately.

It is evident that the greatest care is needed to devise such mechanism and methods as will secure the maximum accuracy of measurement and sampling of the air and of determination of the respiratory products. In the large amount of work done during the last thirty years with various modifications of the Pettenkofer apparatus the chief difficulties have been in the measurement of the air and determinations of the water. The method generally followed has been to measure both the total volume of air and the volume of the samples by gas meters, and to use the samples for determining the carbon dioxid and water by absorption and the marsh gas and other volatile organic compounds by combustion.

The same general method has been followed in these experiments. The air was drawn through the apparatus by means of specially devised air pumps, and its total volume measured by a gas meter especially constructed for the purpose. The samples of incoming and outgoing air were drawn by means of aspirators, the carbon dioxid in the sample was determined by absorption by soda lime, and the water by absorption by sulphuric acid.

As the air was drawn and not forced through the apparatus, and especial pains were taken to make both the respiration chamber and the connecting pipes as nearly air-tight as possible, it was believed that the air which passed through the meter and was measured by it represented very accurately that which had passed through the chamber and received the products of respiration. It is not certain that the chamber was absolutely air-tight, but at no place could any current of incoming air other than that passing through the entrance and exit tubes be found sufficient to affect the flame of a candle. Indeed, it was hardly expected that any considerable quantity of air could enter or pass out in any other way even if the chamber had not been tight, since

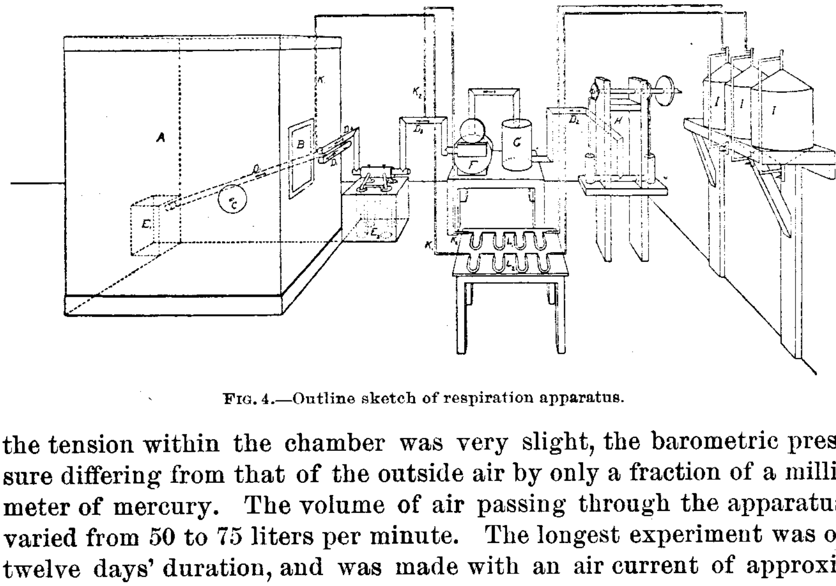

FIG. 4.—Outline sketch of respiration apparatus.

the tension within the chamber was very slight, the barometric pressure differing from that of the outside air by only a fraction of a millimeter of mercury. The volume of air passing through the apparatus varied from 50 to 75 liters per minute. The longest experiment was of twelve days' duration, and was made with an air current of approximately 55 liters per minute.

It is desirable to have the incoming current of air as dry as possible, as stated above. The smaller and more uniform the amounts of water the easier and more accurate are the analytical determinations, and, furthermore, the amount of ventilation needed for the comfort of the occupant of the chamber is less with little than with much moisture. To reduce the amount to a minimum the air which came from out of doors was dried before it entered the chamber. This drying was easily accomplished by surrounding a portion of the pipe through which it passed with a freezing mixture of salt and ice.

The course of the air in its passage from outside through the different parts of the apparatus to the pumps was as follows (see fig. 4): It entered through a window by a pipe of 7.5 centimeters internal diameter and was drawn through a freezer (E_1) consisting of a system of 10-centimeter copper pipes packed in ice and salt; thence it was again conveyed by the 7.5-centimeter air pipe (D_1) to the smaller air pipe which passes through the front wall of the apparatus at the right of the window (B) and about 1.2 meters from the bottom of the chamber (A). In its passage from the freezer to the chamber it was warmed so that it entered the latter at the desired temperature. The warming was done by a 16-candlepower incandescent electric lamp placed inside the air pipe. In this way the temperature of the entering current of air was easily regulated. The air entering the chamber makes a direct downward turn through a copper pipe 10 centimeters in diameter which opens into the lower right-hand front corner of the chamber. The outgoing air is drawn from the upper left-hand corner of the rear end of the chamber, i. e., from a point diagonally opposite that at which the incoming air is delivered. It is conveyed from the latter point by a 10-centimeter copper tube along the top of the chamber to the front end and then downward to the copper tube (D_2) through which it passes out. In this way a favorable distribution of the air in the chamber is obtained. The diameter of the brass tubes has proven ample for the uninterrupted passage of such currents of air as have been found desirable for the experiment. On coming out of the chamber the ventilating current of air was passed through another freezing apparatus (E_2) by which the larger part of the moisture was collected. Thence it passed through the meter (F) by which its volume was measured and onward to the air pump (H). Since, however, the action of the pump would vary the tension, a tension equalizer (G) was placed between the pump and the meter.

Samples of the incoming air were taken from the entrance pipe just as it entered the chamber. Samples of the outgoing air were likewise taken from the exit pipes just as it entered the meter.

The several parts of this apparatus for maintenance and measuring the current of air may be described in more detail as follows:

AIR PUMP.

Two piston pumps were used for drawing the air through the apparatus. They were so arranged that either could be used alone for a smaller current, or the two together for a larger current. In most of the experiments here described, however, only one pump was used. The piston of each pump was moved in a brass cylinder by cranks at the end of a shaft, so that each pump made a double stroke for each revolution of the shaft. This shaft was belted to the main shaft, which works directly from the motor, and runs at the rate of about 300 revolutions per minute. The connections were such that the pump made in general about 75 strokes per minute. The strokes were recorded by an ordinary automatic register reading to 100,000. As the volume of air per stroke was known approximately this record made a rough check upon the measurements with the meter. Desirable changes in the rate of flow of air through the pump are effected by varying the length of the stroke, the devices for this purpose being such that the desired changes could be made with ease and accuracy. When one of the pumps drew 65 liters per minute each stroke represented approximately 0.7 liter.

TENSION EQUALIZER.

When the pumps were connected directly with the meter the motion of the latter was intermittent on account of the variations in air pressure with each stroke of the pump. To reduce these variations of tension to a minimum and make the pressure of the air as it passed through the meter more uniform a device was employed to which the name tension equalizer was given. This was placed so that the air passed through it in going from the meter to the pump. It consists of a cylinder about 50 centimeters high and 40 centimeters in diameter. The sides and bottom of this are of tin plate. Over the top a piece of rubber sheeting, such as is used by dentists, is loosely stretched and tightly bound. Although its capacity is only between 50 and 60 liters, yet the action of the rubber top was such that the variation in pressure of the meter as measured by a water column amounted to only a few millimeters, and no irregularity could be seen in the motion of the index on the meter.

METER FOR MEASURING AIR.

The meter[1] was of the kind employed by Professor Zuntz, of the Agricultural Institute of the University of Berlin, in his respiration experiments with horses, dogs, and other animals, and with man. Professor Zuntz was so kind as not only to assist in getting the meter, but also to test it in his laboratory. The apparatus has been briefly described by Professor Zuntz,[2] and only the essential features will be noticed here.

The readings of the meter are indicated by hands revolving on a large dial and recording to 10,000 liters. In the experiments the meter is read for the number of thousands of liters, while the numbers of ten thousands of liters were checked by the register above referred to under the head of "Air pump" (p. 18).

The accuracy of measurements of volumes of air by a gas meter has been a subject of much discussion and no little experimenting, and the attention given to it in this laboratory has been not inconsiderable. The errors involved are undoubtedly small, and with care may, it is believed, be reduced to a very small fraction of the total volume of air to be measured.

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[1] Made by S. Elster, of Berlin.

[2] Landw. Jahrb., 18 (1889), p. 1; also Flügge, Hygienische Untersuchungsmethoden, p. 531.

In using the meter a thermometer was inserted at one side, so that its bulb was immersed in the water within the meter and its readings were taken as indicating the temperature of the water. This was assumed to be also the temperature of the air as it left the water. The air was assumed to be saturated with aqueous vapor at that temperature. As the air passed through at the slow rate of from 55 to 80 liters per minute, it was not believed that this assumption involved a very large error. It was believed, however, that means could be found by which the errors of measurement could be materially reduced. An apparatus for the purpose has been devised and made by Mr. O. S. Blakeslee, and the preliminary observations made with it are quite satisfactory. It is practically a large mercury pump, so arranged as to serve the double purpose of maintaining the current of air and delivering aliquot samples for analysis.

ASPIRATORS FOR SAMPLING AIR.

The samples of air for analysis were drawn by means of aspirators (I). These aspirators, three in number, are cylinders of galvanized iron, standing upright, with conical ends. The cylinders are 56 centimeters in diameter and 46 centimeters in height, exclusive of the cones which form the ends. The cones are approximately 8 centimeters in height, making the whole length of the cylinder, from apex to apex, about 62 centimeters. At the apex of each cone is a short neck of brass tubing. Horizontal tubes connect the two necks with an upright glass tube on the side of the aspirator. This serves as a gauge and shows the height of the water. It is accurately marked at the top and bottom, and thus permits the drawing off of a definite quantity of water and consequently the accurate measurement of the volume. The aspirators are sustained in a framework and set in cement to give them firm support. At the top of each is a 3-way valve, which serves to make connections with the tubes (K_1 and K_2) bringing the samples of air. A manometer indicates the tension and a thermometer the temperature of the air in the aspirators. Here again the air was assumed in the experiments to be saturated at the temperature indicated by the thermometer. The volume of water or air held by each of these aspirators was determined by weighing the water which it held, and was from 150 to 163 liters. The connection between the aspirators and the tubes, through which the main current of air passes, was made by 6-centimeter brass tubes. The sample currents of air are brought from the main air current through these small brass tubes into the apparatus for the absorption of carbon dioxid and water (L_1 and L_2) and then into the aspirators, by which the samples are drawn and the volume of each sample is measured.

The rate of flow is regulated in a very simple manner. The water passes out from the bottom of the aspirators through a short brass tube which is connected with a longer rubber tube. The last is provided with a screw pinchcock and a metallic nozzle at the lower end, which is raised or lowered at will, thus varying the head of water. In taking a sample, the aspirator is first filled to the mark indicated on the water gauge outside. The connection is made by the 3-way cock with the tube through which the sample of air is drawn from the main current. The flow of water from the bottom is started with the nozzle at the end of the rubber tube at the height of about 1 meter from the floor. The water which first comes out is collected in a graduated cylinder. The amount in one minute shows the rate of flow. If this is too fast or too slow, it is changed by means of the pinchcock on the rubber tube. When the proper flow is established, ordinarily about 500 or 600 cubic centimeters per minute, it is allowed to proceed. As the water level in the aspirator falls, the nozzle is lowered and the rate of flow is observed at intervals, generally of about one-half hour. In this way it is easy to make the rate rapid or slow at discretion and reasonably uniform.

APPARATUS FOR DETERMINING CARBON DIOXID AND WATER IN SAMPLES OF AIR.

The constituents of the air determined in the experiments described beyond were carbon dioxid and aqueous vapor, although only the former is reported. The device above referred to (p. 17) for removing the moisture from the main air current by cooling to about -17° C. leaves a small and fairly uniform amount of moisture, and thus greatly facilitates the determination of the latter in the samples analyzed. Four U-tubes are used for the analysis, two, filled with soda-lime, for the carbon dioxid, and two, containing sulphuric acid, for the water of each sample. For weighing they are hung by loops of platinum or aluminum wire.

Freezing apparatus.—It was found very desirable in these experiments to have the air enter the respiration chamber as dry as possible. It was with this fact in view that the plan was first adopted for freezing the air before it entered the chamber. The freezer used for this purpose consists practically of two large U-tubes of copper. These are connected with each other and with the pipe through which the current of incoming air flows. They stand upright in a wooden box which is kept filled with a freezing mixture of salt and ice. Each of the four uprights of the two U-tubes consists of a pipe made of (No. 16) sheet copper, 10 centimeters in diameter and 91.4 centimeters in length. These upright pipes are so connected by horizontal elbows that the whole forms a compact mass 1 meter in length and a little over 20 centimeters square. In this way the current of air has to pass through nearly 3.65 meters of copper tubing which is covered by the freezing mixture. To still further increase the cooling surface of metal, and with it the rapidity of the passage of heat from the air to the freezing mixture, a number of vanes of sheet copper are placed inside the four lengths of copper tubing. Each vane is parallel with the axis of the tube and is soldered to the side so as to project 3.8 centimeters toward the center in a radial direction. In the horizontal elbow through which the air, after having passed through the four tubes, returns to the main conducting pipe is an orifice in which is inserted a thermometer. This indicated the temperature of the air as it left the freezer, under ordinary conditions to be from about —17° to —18° C. The wooden box which held the freezing mixture and the freezing apparatus had at the bottom an outlet for the brine. The ice was finely crushed, mixed with salt, and packed closely between the freezer and the box.

When the experiment was continued for twelve days, the moisture which gathered in the form of frost on the inside of the freezing apparatus accumulated so as to retard the passage of the current. Accordingly the pump was stopped in the middle of the experiment, the freezer taken out, and hot water poured upon it so as to melt the ice inside. It was then emptied, put back in place, and repacked in the freezing mixture. The whole operation did not last more than twenty minutes. The stoppage of the current of air during this time did not cause the least discomfort to the person inside the chamber. Indeed, he was not aware of it until he was told.

It was found necessary to repack the space outside the freezer with ice and salt about once in two hours under ordinary conditions. This method of removing the excess of moisture from the air before it enters the chamber proved so satisfactory as to lead to its adoption in quantitative determinations of the moisture in the outgoing air. For this purpose, however, a somewhat more complicated freezer is necessitated by the fact that the water which it collects must be accurately weighed. The detailed description of this freezer is reserved for future publication.

Objections to the use of ice and salt for freezing are the trouble of frequent renewal, the expense for material and labor, which was not inconsiderable, the difficulty of getting a satisfactory low temperature, and especially the impossibility of maintaining a constant temperature. For the later experiments immersing the freezers in brine cooled by the expansion of ammonia gas has been adopted.[1]

METHODS OF SAMPLING AND ANALYSIS.

ANALYSIS OF FOOD, FECES, AND URINE.

The methods of analysis used were essentially those adopted by the Association of Official Agricultural Chemists, with such modifications as experience and circumstances have shown to be desirable.[2]

PREPARATION AND SAMPLING OF FOOD.

In the preparation of the food special effort was made to secure such mechanical condition of the materials as would facilitate the most thorough and accurate sampling. The samples, when too moist for

[1] The so-called "Economical Ice Machine," made by the Atlantic Refrigerating Company, of Springfield, Mass., has been found very satisfactory for this purpose.

[2] For detailed descriptions of the usual methods followed, with the possible sources of error involved, see U. S. Dept. Agr., Division of Chemistry Bul. 46; Office of Experiment Stations Buls. 21, pp. 39–52, and 29, pp. 8, 9.

grinding, were partially dried; the material in the original or partially dried form was sampled and ground, first in an ordinary "Excelsior mill," afterwards in a Maercker-Dreefs mill, by which it is easily reduced to a very fine powder. Some materials, containing considerable quantities of fat or sugars, are not easily ground in this way. Meats, eggs, and canned pears, for instance, were rubbed in a mortar until they were homogeneous. The ground material was preserved for analysis in tightly stoppered bottles. It has been found, however, that when such materials are kept in bottles closed with glass, or even rubber stoppers, they are apt to change in moisture content on long standing. Unless the analyses are to be made immediately, or within three or four days at longest, it is best to seal glass-stoppered bottles with paraffin. Even then, if the material has stood for some weeks, it will sometimes be found desirable to repeat the determinations of moisture. When nearly all the water is removed from the materials, as is done in the process of partial drying referred to beyond (p. 24), no indications of decomposition, even of meats, were found for some weeks or months. It is, however, noticeable that when the samples of meats containing more or less fat are thus dried and finely ground, and are allowed to stand in the working room of the laboratory, the fat gradually separates and settles to the bottom of the bottle. This is an indication of the need of careful mixing of such materials just before the weighing of portions for analysis.

Some food materials, however, are so dry as not to require the partial drying. Ordinary fine wheat flour is ready for analysis at once, or can be preserved for some time in tightly closed bottles. The coarser flours and meals, rice, and common crackers and biscuit can generally be ground and kept for analysis without drying.

Since in some instances the tréatment was somewhat detailed, the methods used for the preparation of each kind of food for analysis may be briefly outlined.

Beef.—A lean piece of round steak was selected and the superfluous fat was carefully removed. The meat was then cut in long strips and run through a meat chopper several times, thus securing fine division and thorough mixture. After leaving the chopper it was weighed out in balls or cakes of 62½ grams each, and placed on a plate covered with a glass cover. When meat was cooked for a meal three of these balls were cooked at the same time and in the same dish; two of them were eaten, and the third served as a sample for analysis.

Bread.—Three kinds were used, "white bread," made of fine wheat flour; "brown bread," of wheat and rye flour and corn meal; and rye bread. To insure like composition and like proportions of crust and crumb, the loaf was cut in slices and alternate slices were taken for eating and analysis.

Oatmeal.—One of the common commercial preparations of oatmeal was used. A certain weight of the dry material was cooked in water. As there was no reason to fear loss of material the composition of the oatmeal as eaten was assumed from that of the original material, taking into account the water added in cooking.

Potatoes.—These were boiled with the skins on. After pouring off the water the skins were removed and the potatoes put through a potato masher. The portion to be eaten was weighed, a sample of like weight being taken at the same time for analysis.

Apples.—The fresh fruit was pared and the cores removed, nothing but the apple pulp being eaten by the subject. Samples of the pulp were analyzed.

Canned beans, pears, and peaches.—These three materials were served cold, and required no special preparation. Samples from the different cans were used for analysis.

Milk crackers, sugar, and cheese.—These were served as purchased in the market, without any special preparation. Samples of each lot were analyzed.

Eggs.—Eggs of approximately the same weight were selected. Three were boiled in the same dish of water, two were eaten, and one was taken as a sample.

Butter.—This was a creamery butter as purchased. No partial drying was necessary. Samples were taken at each meal, each sample being of the same weight as the portion eaten.

Milk.—Aliquot portions were taken from the milk of each day. These samples were preserved until analyzed by addition of potassium bichromate.

As fast as samples were taken they were either immediately "partially dried," as in the case of meat, bread, potatoes, etc., or preserved for future analysis by some antiseptic, such as potassium bichromate, as in the case of milk. The several samples of a given material for a given period were joined together and resampled, so that a single analysis served for the whole of that special lot. Thus the several samples of "white" bread for a given number of days were united, and after the partial drying were well mixed and a single sample representing the whole was analyzed. This course was followed with the other materials in so far as it was feasible without risk of inaccuracy.

WATER.

Partial drying.—For this process portions of 50 grams each were placed in shallow porcelain sauce dishes and heated in a large air bath at the usual temperature of 96° C. or thereabouts for a period of thirty-six hours. They were then placed on a shelf lightly covered with paper, and thus exposed to the air in the laboratory for twenty-four hours. At the end of this time the moisture content had become practically constant and the samples were weighed and the loss of moisture noted. They were then ground, placed in properly marked bottles, and set aside for analysis.

Complete drying.—For the determination of water-free substance the usual methods were employed. The time of drying was usually five hours, in accordance with the official methods. This, however, did not suffice in all cases, and longer heating was necessary. It is well known that one of the most difficult operations in the laboratory is the accurate determination of moisture in animal and vegetable substances, and not a little work has been done in this laboratory with a view to improving the accuracy of moisture determinations.[1]

FAT—ETHER EXTRACT.

The sample which had been dried in hydrogen for the water determination was used for the determination of crude fat. To this end it was extracted in the usual way with ether, which had been digested with fused calcium chlorid and distilled over that substance. Continuous extraction for sixteen hours was generally sufficient.

ASH.

For determination of ash the material was incinerated in the following manner: The mass was first charred in a platinum capsule and then extracted with hot distilled water, the insoluble matter being collected on a filter; the filter with its contents was then returned to the platinum capsule and the whole heated until the incineration was complete. The aqueous extract was added, and after evaporation the whole residue was heated at low redness until the ash was white.

NITROGEN—PROTEIN.

Nitrogen was determined by the Kjeldahl method, the amount of nitrogen thus found multiplied by 6.25 being taken as representing the protein. As the proportion of nitrogen is the basis of the calculations of nitrogen balance, the method of estimating protein by differences, which is often followed in analysis of meats and other materials containing little or no carbohydrates and which is doubtless often more accurate, would not be in place here.

Experience in this laboratory with meats and other animal tissues confirms the observations of other chemists that there is great danger of incomplete ammonification of the nitrogen in these substances when treated with sulphuric acid and other reagents as ordinarily recommended in the Kjeldahl process. It appears that numerous albuminoid substances resist decomposition, or at any rate the complete union of nitrogen and hydrogen to form ammonia. With such substances it was found necessary to continue the digestion for some time after the sulphuric-acid solution had become colorless. The clearness of the solution was by no means an indication of complete ammonification. The process has frequently been found to be incomplete when the digestion had been continued for an hour or even two hours after the disappearance of color. It is safer to continue the digestion for three or four hours after the solution has become decolorized.

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[1] See U. S. Dept. Agr., Office of Experiment Stations Bul. 21, p. 41.

Casein.—In analysis of butter the casein was determined directly. The butter was placed in a Gooch crucible and the fat dissolved out with ether. The casein and mineral matters were weighed together and the casein burned. The loss in weight on burning was taken as representing the casein. The danger of slight error here on account of the presence of milk sugar is a subject which has not been investigated.

CARBON AND HYDROGEN.

The food materials, feces, and dried urine were burned with cupric oxid with the aid of a current of oxygen, in accordance with the usual methods. The carbon dioxid was absorbed by potassium hydroxid and the water by concentrated sulphuric acid.[1]

HEATS OF COMBUSTION—FUEL VALUES.

The determinations of heats of combustion of food materials, feces, and dried residue of urine were made with the bomb calorimeter, as described in previous publications.[2] The apparatus and method have been in use in this laboratory for the past three years, and have been found very satisfactory.

COLLECTING, PRESERVING, AND SAMPLING OF FECES AND URINE.

In the digestion experiments (which began before the subject entered the respiration chamber, as explained beyond) it was necessary that the feces of a given diet should be separated from those of the diet immediately preceding. To effect a sharp separation the subject had a supper of bread and milk, at which time he took six or seven large gelatin capsules containing lampblack.[3] The following morning the diet decided upon for the digestion experiment was begun and strictly adhered to throughout the whole experiment. The sampling of food for analysis was also begun at this first meal. On the second or third day the milk feces, having a characteristic consistency and colored with lampblack, generally appeared. When there was no indication of diarrhea, the separation of the residues from the two different kinds of food may be considered reasonably accurate inasmuch as the portion from the meal of bread and milk is easily distinguished from that of the succeeding meal. All the feces following that of the bread and milk were saved. At the end of the experiment a supper of bread and milk with lampblack was again taken, and all the feces up to the point where the milk residue appeared were considered as belonging to the undigested residues of the diet under study. At first the feces of each day during the experiment were separated, weighed, and in

[1] For observations upon the sources of error in the ordinary methods of analysis of animal and vegetable products, see U. S. Dept. Agr., Office of Experiment Stations Bul. 21, pp. 38–52.

[2] U. S. Dept. Agr., Office of Experiment Stations Bul. 21, pp. 123–126; Connecticut Storrs Sta. Rpt. 1894, pp. 135–157.

[3] Later experience has shown that so much lampblack is unnecessary.

some cases separately analyzed also. This, however, proved unnecessary, as it was found that the composition with a given diet remained very nearly the same from day to day.

The urine is obviously a very important factor as regards the metabolism of nitrogen. Consequently its collection and preservation for analysis require especial attention. Unfortunately it was possible to give only limited attention to the subject during these experiments. It is believed that a more thorough investigation of the character and constituents of urine in respiration experiments will prove of no little physiological importance.

In these experiments the bladder was emptied every morning at 6 o'clock. All the urine voided between that hour and the next morning at the same hour was taken as the urine for that day. Each day's urine was carefully weighed, thymol being added as a preserving agent.

The total nitrogen in the urine was determined in the fresh substance by the Kjeldahl method.

For the determination of carbon and hydrogen the urine was dried in a partial vacuum over sulphuric acid. It was found by repeated tests that drying urine by heat involves considerable loss of nitrogen. The importance of avoiding this loss led to investigations which showed that fresh urine could be dried in a vacuum over sulphuric acid without material loss of nitrogen. Accordingly it was assumed that there would also be extremely little loss of carbon and hydrogen, and the substance thus dried was taken for the determinations of these elements. The same method was followed, though generally with a somewhat longer period of drying, to determine the amount of water-free substance. The percentage of water in this "partially dried *in vacuo*" urine was taken into account in calculating the percentage of carbon as determined by combustion with cupric oxid.

ANALYSIS OF RESPIRATORY PRODUCTS.

In experiments of the class to which those here reported belong the respiratory products commonly determined are carbon dioxid, water, and volatile organic compounds.

CARBON DIOXID.

The determination of carbon dioxid is most essential, and is, of course, always attempted. The experience of a number of experimenters during the past twenty-five years implies that the difficulties in the way of fairly accurate results are not insuperable. The carbon dioxid given off in respiration is quickly diffused through the air and readily conveyed away by the ventilating current, so that the accurate measurement of that current and determination of the percentage of carbon dioxid suffices for the ordinary purposes of experiment.

For the absorption of carbon dioxid soda-lime has, in our experience, proved the most satisfactory reagent. It must, however, have the proper proportions of soda, lime, and water to fit it for the purpose. It may be made as follows: One kilogram of commercial caustic soda is treated with 600 cubic centimeters of water, forming a very strong solution, or rather a pasty mass. To this a kilogram of quicklime is added. The latter is slaked by the water of the soda solution. The mixture is rapidly stirred. No heating is necessary. If there are any lumps, they are broken into small pieces, and the soda-lime thus made is immediately put into large bottles or fruit jars and tightly sealed.

The presence of a certain amount of moisture in the soda-lime is essential to the complete absorption of the carbon dioxid. As the soda-lime is converted into the carbonates of sodium and calcium the mass whitens, and the advancement of this change in color from one end of the column of soda-lime to the other is apparent as the absorption of carbon dioxid proceeds. This affords a very good check on the efficiency of the tube. In the preliminary tests of the method, as in the actual determinations, two tubes were used in series, and after each determination the second tube was moved toward the incoming current, so that it became the first tube, and a fresh one was inserted to serve as second tube. Numerous experiments were made with varying quantities of carbon dioxid in the air and with varying rates of flow to see if the system would thoroughly remove all carbon dioxid. A check tube containing glass beads drenched with barium-hydroxid solution failed to indicate the slightest trace of carbon dioxid, with 150 liters of aspirated air, containing 3.5 grams of carbon dioxid, and running at the rate of 500 cubic centimeters per minute.

The value of the soda-lime as an absorbent for carbon dioxid was further demonstrated by passing a current of air previously freed from carbon dioxid through a flask in which a known quantity of carbon dioxid was generated from pure sodium carbonate or calcite. As the air with this carbon dioxid came from the flask it was passed over sulphuric acid to absorb the water and then through two tubes containing soda-lime, then through a tube with sulphuric acid to catch the water set free from the soda-lime, and finally through a tube containing barium-hydroxid solution to detect any traces of carbon dioxid which might fail to be absorbed by the soda-lime.

After considerable experience in testing the methods by control experiments of various kinds an arrangement of absorption tubes for water and carbon dioxid was settled upon, and has since proved very satisfactory. The order is: First, a tube filled with pumice stone saturated with sulphuric acid for the removal of water; then two tubes filled with soda lime for the absorption of the carbon dioxid; and finally a sulphuric-acid tube to absorb the water removed from the soda-lime by the current of air and set free in the formation of carbonates by the action of the carbon dioxid upon the hydroxids.

It was found important, however, to pass a current of dry air through the sulphuric-acid tubes for three or four hours before they were used for the determinations, since it was observed that the freshly filled tubes lost weight when dry air was first drawn through them, the loss sometimes amounting to 20 milligrams. A plausible explanation of this loss would be found in the assumption that incompletely oxidized compounds of sulphur or nitrogen which were either originally present in the acid or were formed by its action on the organic matter in the pumice stone were removed by the air when first passed through the tube. As the method for avoiding the error proved simple and effective, we have not taken the time to inquire more fully into the cause.

The determination of carbon dioxid by the above method is quite satisfactory, as was shown by numerous control experiments. In one experiment, for instance, which was fairly representative of all, 1.6692 grams of carbon dioxid were delivered into the air current and 1.6718 grams were removed in the soda-lime.

The weighings were all made with a counterpoise. To insure equal moisture condensation on the tubes and counterpoise, the latter was kept in the tray with the U-tubes, and hence subjected to like conditions of temperature and moisture.

WATER.

The accurate determination of water has been found less easy. The difficulty appears to rest not so much in the determination of moisture in the current of air as in the getting of all the moisture into the current. It is believed that one chief trouble here may be the adhering of moisture to the surfaces of the walls and other interior parts of the apparatus and its absorption by the clothing of the subject and the furniture in the respiration chamber. It is evident that for reliable results two things are requisite. One is an accurate and convenient method for the determination of water in a current of air, the other a means for either making sure that all the water to be determined is contained in the air current or that the amount not in that current shall be determined in some other way. The water to be determined is the whole given off from the body of the subject in the respiration chamber, less the amount removed in feces and urine. Practically this means the water exhaled through the lungs and skin. For our present purpose it may be designated as water of exhalation and taken as including the water of respiration from the lungs and that of perspiration from the skin. Since the various difficulties encountered in the accurate determination of water had not been satisfactorily overcome when these experiments were made, the results of such determinations are not reported in this article.

The test of the reliability of the methods for the determination of the products given off from the body of the person in the respiration chamber must be found in check experiments in which known quantities of the same products will be given off in the chamber and determined in the air current by the methods used for the actual experiments.

Numerous check experiments of this kind preceded the experiments with men reported beyond. The results indicated that the determinations of carbon dioxid were reasonably accurate. The same was also true of the water as far as concerned the amounts actually contained in the incoming and outgoing currents of air. It was not certain, however, that the moisture which was condensed upon the interior surface of the apparatus (especially upon that part of the apparatus within the chamber through which the cold water passed to carry away the heat and to which the term heat absorbers has been applied) was the same at the beginning as at the end of the experiment. The assumption that the methods for the determination of carbon dioxid and water in the currents of air and for the determinations of the amounts of carbonic acid in the apparatus were reasonably accurate was further substantiated by check experiments which followed the present experiments with men.

The most satisfactory of these were made by burning ethyl alcohol inside the chamber. The determinations of carbonic acid differed by less than one-half of 1 per cent from the theoretical. In other words, for every 100 grams of carbon in the alcohol the measurements gave from 99.9 to 100.4 grams. So far as concerns the determination of carbonic acid given off inside the apparatus, the only difference between these check experiments with alcohol and the experiments with men reported beyond was in the measurement of the air current, which could hardly have made any very important difference in the results. It is believed, therefore, that the determination of carbon dioxid given off by the men in the experiments beyond can not be very far from correct.[1]

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[1] Before the check experiments were made, arrangements were perfected by which the absorption apparatus could be weighed by the man inside the chamber, so that the changes in the amounts of water condensed upon the surface of the absorbers could be learned. The measurements of the volume of the air were made by the improved apparatus referred to above. (See p. 20.)

In the check experiments with alcohol the determinations of water could not be made with the same accuracy as in the experiments with men, since in the latter case the absorption apparatus could be weighed by the person inside the chamber. It is, however, possible so to regulate the combustion of the alcohol, and hence the production of carbon dioxid, water, and heat, that the amounts produced during a given period at the beginning of an experiment shall be very nearly the same as during a like period at the end. Under these circumstances the amounts of water condensed on the absorbers at the ends of the two periods will be approximately the same. The control of the amount of water condensed upon the absorbers is facilitated by the ease with which both the temperature of the interior of the apparatus and the proportion of water in the incoming air current may be regulated.

In the check experiments made by burning alcohol in the chamber, pains were taken to make the conditions of (1) temperature of interior of apparatus, (2) amount of moisture brought into the apparatus by the incoming current of air, and (3) the rate of combustion of alcohol approximately alike at the beginning and at the end of each experiment. These periods were six hours or more each. The experiments proper began at the end of the first period and ended at the close of the second

VOLATILE ORGANIC COMPOUNDS.

It has been found necessary in experiments with some animals, e. g., oxen, to determine the quantities of carbon in the hydrocarbons and other volatile organic compounds given off from the body. Of these the most important appears to be marsh gas produced by the fermentative action of bacteria in the large intestine. With men the quantity of such compounds produced is apparently very small. They were not determined in the experiments here reported, although it will doubtless be necessary to look for such compounds and perhaps to determine quantitatively their content of carbon and hydrogen in experiments where the greatest accuracy is sought.

THE EXPERIMENTS.

The factors involved in a complete metabolism experiment and in what is commonly called a respiration experiment are fully explained on page 7. For reasons already given, the account of the respiration experiments here reported include only the results of measurements of the income and outgo of nitrogen and carbon. The factors actually determined and reported are:

Income.—Food, drink, and their content of nitrogen, carbon, protein (N × 6.25), fats (ether extract), carbohydrates (by difference), mineral matter (ash).

Outgo.—Respiratory products—carbon dioxid and its content of carbon.

Feces—nitrogen, carbon, protein (N × 6.25), fats (ether extract), carbohydrates (by difference), mineral matters (ash).

Urine—nitrogen, carbon.

As above explained, the experiments here reported involved digestion experiments. The results of the latter are included in the descriptions which follow. The determination of the digestibility of the several nutrients of the food was made in the usual way, by comparing the amounts of protein fat, carbohydrates, and mineral matter in the food and feces.[1] The results of the digestion experiments, however, misrepresent the actual digestion of the food by practically the amount of the metabolic products in the feces. The error, however, is not large, and, so far as the respiration experiments are concerned, it may be left out of account entirely, since the question is the balance of total actual income and outgo of chemical elements and the metabolic products of the feces are as truly a part of the outgo as the undigested residue of the food.

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period, and covered generally from twenty-four to forty-eight hours. The determinations of water in the three check experiments ranged from 100.1 to 100.3 per cent of the theoretical amount. Improvements were also made in the arrangements for the determination of the quantities of heat given off by the body.

[1] See discussion of this subject in U. S. Dept. Agr., Office of Experiment Stations Bul. 21, pp. 56–73.

THE DIET.

In these experiments the effort was made to have the conditions as nearly normal as possible. To this end it was essential that: (1) The diet be such as to agree with the subject, and (2) the quantities of nutrients be such as to meet the actual needs of the body under the conditions in which the subject was placed during the experiment.

To facilitate the right choice of the diet, observations on the ordinary diet of the subject and a preliminary test of a number of days were considered essential. Accordingly the subject was allowed to select his own diet from a bill of fare limited only by the skill and appliances for cooking available. In this way the selection of food was made such as to suit the palate and not become so monotonous as to cause nausea or any other derangement of the processes of digestion. The subjects were inclined to take more food than was necessary for the rather inactive life in the respiration chamber. It was important to provide that the regimen during the experiment should be not only such as would meet the actual needs as regards kinds and amounts of nutrients, but should also be the same from day to day.

The latter point is especially necessary. The actual income for a given day or a given number of days is the amount digested and absorbed during that period. If the food varies from day to day there is no convenient means of learning to what extent the proportions of nutrients digested vary with the food. Or, to put it in another way, with varying diet the coefficients of digestibility of the several nutrients, protein, fats, and carbohydrates, may change and it will be impossible to tell how much is digested from each day's ration unless a separate digestion experiment is made each day, which latter would either reduce the period of each experiment to one day or involve very considerable difficulties in the separation of the feces for each day. Furthermore, only part of the food taken on a given day is absorbed and used in the body on that day, and it is impossible to tell just when the period during which it is being used begins and ends. If, therefore, the diet varies from day to day, there is no way to learn how the variation affects the amounts actually absorbed from the alimentary canal and used by the body on the different days during and immediately following the days when the changes are made.

These considerations bring out one of the chief sources of uncertainty in such experiments, namely, the impossibility of measuring exactly the amount of material actually taken from the digestive tract and brought into use by the body during a specified period. It seemed that the error would be materially reduced, if not eliminated, by providing the subject with a uniform diet for a long period and letting the actual experiment be for a shorter period included within this longer period. This gives an opportunity to utilize the longer period for a digestion experiment, the results of which may be taken as a measure of the quantities of nutrients taken up and used during the metabolism experiment.

In accordance with these considerations, the subject commenced a specified regimen some days in advance of each experiment. To adjust the quantities of food materials, so as to secure the proper proportions of nutrients, estimates were made in advance by use of the figures for composition of American materials.[1] The exact amounts of protein, fats, and carbohydrates were, of course, not learned until the analyses were made. Fortunately, the actual composition as thus found was very close to the advance estimates in every case.

Meals were eaten three times daily at regular hours, thus conforming as far as possible to ordinary custom. Drinking water was allowed at all times, the weight used and the temperature, however, being carefully noted. The freedom allowed in the selection of diet added, it is believed, materially to the success of the experiment, although the number of different materials made the analyses quite laborious.

Although the diet in each experiment was comparatively simple, a considerable number of food materials were analyzed. The composition of the various foods is given in the following table:

TABLE 1.—*Composition of food materials used in the experiments.*

Laboratory number.		Experiment number.	Nitrogen.	Carbon.	Hydrogen.	Water.	Protein (N × 6.25).	Fat.	Carbohydrates.	Ash.	Fuel value per gram.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Calories.*
2696	Beef, fried	1	4.64	21.24	3.35	58.9	29.0	9.8	1.0	1.3	2.494
2699	do	2	4.85	23.00	3.43	56.4	30.3	11.1	.7	1.5	2.758
2704	do	3	4.73	20.26	2.91	60.3	29.6	8.1	....	2.0	2.424
2715	do	4	5.48	23.18	3.46	53.5	34.2	10.4	....	2.0	2.904
2695	Eggs, boiled	1	2.07	14.45	2.25	73.3	12.9	11.3	....	1.0	1.897
2698	do	2	1.99	14.95	2.42	72.4	12.4	13.0	....	1.0	2.043
2705	do	3	2.41	15.43	2.55	69.2	15.1	13.2	....	1.1	2.123
4238	Butter	1	.14	64.64	9.69	9.2	.9	86.3	....	3.6	8.122
4239	do	2	.16	66.40	9.69	8.9	1.0	85.4	....	4.7	8.184
4248	do	3	.14	67.07	9.78	8.1	.9	88.4	....	2.7	8.435
4249	do	4	.18	66.85	9.80	8.9	1.1	86.9	....	3.1	8.169
4228	Cheese *a*	1	4.29	33.43	4.88	44.1	26.8	24.5	1.2	3.4	3.800
4237	do *a*	2	4.07	35.80	5.26	39.7	25.4	27.0	4.0	3.9	4.219
4227	Milk	1	.58	7.27	.94	85.9	3.6	4.2	5.5	.8	.836
4240	do	2	.54	6.79	1.00	85.9	3.4	4.5	5.5	.7	.822
4247	do	3	.53	6.17	1.02	85.9	3.3	4.5	5.5	.8	.807
4250	do	4	.53	6.01	1.00	86.2	3.3	4.2	5.6	.7	.798
2697	Crackers, milk	1	1.78	44.00	6.54	5.7	11.1	12.3	69.6	1.3	4.677
2701	do	2	1.67	44.01	7.08	5.5	10.4	12.2	69.3	2.6	4.679
2693	Bread, rye	1	1.47	25.85	2.37	39.0	9.2	.2	50.3	1.3	2.681
2703	do	2	1.43	25.63	3.97	40.4	9.0	.2	49.0	1.4	2.607
2724	Bread, white	3	1.31	25.83	3.77	39.1	8.2	1.3	50.6	.8	2.735
2727	do	4	1.48	27.82	3.89	35.6	9.2	1.4	52.8	1.0	2.892
2726	Bread, brown	4	.93	22.27	3.13	47.2	5.8	1.2	43.6	2.2	2.305
2723	Oatmeal	4	2.75	41.15	5.83	8.9	17.2	7.0	65.2	1.7	4.409
2728	Beans, dried	4	1.10	11.37	1.57	72.8	6.9	.4	18.0	1.9	1.179
2694	Potatoes, boiled	1	.35	8.00	1.27	80.8	2.2	.1	16.2	.7	.787
2700	do	2	.36	9.54	1.36	76.8	2.3	.1	19.8	1.0	.965
2708	do	3	.37	9.68	1.48	74.8	2.3	.1	21.7	1.1	1.032
2725	do	4	.40	9.77	1.41	75.8	2.5	.1	20.6	1.0	.989
2709	Apples	(*b*)	.04	5.59	.78	86.7	.2	.2	12.7	.2	.547
2707	Peaches	3	.09	4.87	.57	89.3	.6	.1	9.7	.3	.476
2722	Sugar	(*c*)	....	42.06	6.45	....	....	....	100.0	....	3.987

a These two samples of cheese became partially decomposed before the determinations of carbon, hydrogen, and heats of combustion could be made. The figures for factors named have been calculated from the percentages of protein, fats, and carbohydrates by use of the factors 0.53, 0.765, and 0.44, respectively, for the content of carbon, and 0.07, 0.12, and 0.06, respectively, for the hydrogen content; the heats of combustion were calculated from the values previously found in two similar samples.

b Experiments Nos. 3 and 4.

c Experiments Nos. 1, 2, 3, and 4.

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 28.

DAILY ROUTINE.

The digestion experiment which was made with each respiration experiment commenced two or three days before the latter, but both ended at the same time. On the second or third day of the digestion experiment the subject entered the respiration chamber, but, in order to insure normal conditions, the respiration experiment did not begin until six hours after he had entered. This allowed the subject an opportunity for arranging his furniture, the hygrometer, thermometer, and other apparatus in the room, and permitted the establishment of the needed equilibrium of temperature and moisture content in the chamber preparatory to the respiration experiment itself.

The food and drink were passed in and the solid and liquid excreta were removed through the food aperture in the side of the apparatus. A comfortable temperature was maintained within the room by means of a current of cold water, which passed through the pipes of the heat absorbers inside the chamber and thus brought away the heat radiated from the man's body. The temperature which best suited the feelings of the subject, generally not far from 20° C., was maintained throughout the whole of each experiment, except during one period of the last experiment, when the subject was engaged in hard muscular work. In this case a very large amount of heat was given off from the body, and the current of cold water passing through the absorbers did not suffice to prevent the temperature from rising at times to 23° or 24°. As this high temperature was maintained for only a few hours at a time, it is clearly an exception to the rule.

The occupants of the chamber passed the time in such ways as were in general most agreeable under the circumstances. They observed regular hours of eating and sleeping. There was, of course, almost no opportunity for exercise. In the last experiment, however, a special arrangement was made for vigorous muscular labor in lifting and lowering a weight suspended from a pulley. This arrangement will be described in connection with the other details of the experiment. Abundant opportunity was given for reading, considerable conversation was held between the occupant and the men who did the work outside, and the monotony was also relieved from time to time by visitors.

Since the experiments went on day and night, relays of the force for day and night work were, of course, necessary. During the day a force of five or six persons was generally employed. During the night, when the occupant of the chamber was asleep, the force was reduced to three.

A brief description of the routine of one day will perhaps help to a better understanding of the way in which the experiment was carried out. The night force of operators was relieved at 7 o'clock a. m. At that time the subject was awake and ready for breakfast. The assistant, who had charge of the preparation and cooking of the food, prepared the breakfast; the chemist of the night force changed the system of U-tubes for analysis of the air. The day chemist proceeded to start the passage of the air through the fresh system of tubes, and then weighed the system which had just been removed; the readings of the meter by which the ventilating current of air was measured, and of temperature, barometric pressure, etc., were made. The subject, having emptied the bladder at 6 a. m., passed out the liquid, and at the same time the solid excreta. The readings of the hygrometer and thermometer inside the apparatus were taken by the subject on rising, and the observations were repeated once in two hours throughout the day. Naturally, the inquiry regarding the subject's physical condition, and any changes needed, received early attention in the morning.

Breakfast was ordinarily served at about half past 7 o'clock, dinner at about half past 12 o'clock, and supper at 6 o'clock. Drinking water was given whenever desired, its weight and temperature being noted.

The freezing apparatus required repacking with ice and salt about once in two hours during the day and night; the rate of flow of water through the aspirators by which the samples of air for analysis were drawn was regulated every half hour. The temperature of the air of the meter was recorded hourly. The freezers through which the outgoing air passed were changed once in twelve hours, and the water condensed in them was weighed. The absorption tubes for the water and carbon dioxid of the air samples were changed once in six hours, at which time the temperature of the aspirators, the temperature of the meter, and the readings of the meter and of the air-pump register were recorded.

Concurrently with all of these operations, the analytical work was carried on and completed as rapidly as possible.

COMPUTATION OF RESULTS.

NITROGEN BALANCE.

Nitrogen in urine.—In the estimate of nitrogen balance the measure of the nitrogen metabolized in the body during a given period is sought in the nitrogen of the urine for a period of equal length. The period is commonly a day of twenty-four hours. The period for collecting the urine, however, can not be coincident with that for which the nitrogen metabolism is to be measured, since some time is required for the metabolized nitrogen to be conveyed to the kidneys, passed into the bladder, and afterwards excreted in the urine. The twenty-four-hour period for collecting the urine must therefore begin and end later than the corresponding nitrogen-metabolism period of twenty-four hours. This interval, during which the excretion of nitrogen lags behind the metabolism, may for convenience be termed the "nitrogen lag." Unfortunately there are few data for judging accurately as to the length of this interval of lag. Indeed one of the most difficult problems in experiments of this class is to determine the actual source of the nitrogen excreted in the urine—that is, to determine whether the identical nitrogen of the food is excreted in the urine after a short interval, or whether the nitrogen becomes part of the body tissue and an equivalent amount (derived from the body) is excreted.

Kolpakcha[1] has recently made some interesting experiments with dogs which bear on this problem. He compared the ratio of phosphorus and nitrogen and sulphur and nitrogen in the food and urine under various dietary conditions, and also when no food was consumed. These ratios were found to vary under the different dietary conditions. The conclusion was reached that when the food supply was adequate very little nitrogenous tissue was broken down, i. e., the nitrogen excreted actually came from the food. An excess of protein eaten over the amount required was stored up inside the cells of the protein tissue of the body, but was not immediately made a part of the actual tissue. It was simply reserve material. After a few days of fasting, this reserve was exhausted and the body was then compelled to draw on its own protein. Since the above mentioned period is short, the conclusion seems warranted that in the case of dogs the actual nitrogen consumed in the food is soon excreted under ordinary conditions.

In the present experiments a lag of six hours was assumed in one case and a lag of twelve hours in another. The fluctuations in the daily excretion of nitrogen in the experiments herewith reported when the diet and other conditions were reasonably uniform indicate, however, that it is impossible to make any accurate estimate of this interval of lag. These fluctuations are shown in the statistics of the nitrogen excretion in Tables 5, 12, 19, and 26.

It is a familiar fact that some materials may be excreted by the urine within a very short time after they have been taken in the food. Thus it is a common observation that the peculiar odor of urine which comes from asparagus may be observed within an hour after eating the latter. In several rough tests made in this laboratory very small quantities of potassium iodid were administered to a person, and a perceptible test for iodin was obtained in the urine within half an hour after taking the salt.

Such observations as these, however, do not give exact indications of the rapidity of secretion and excretion of metabolized nitrogen. Thus it was found, in experiment No. 4 (p. 51), where the metabolism of nitrogen was materially increased by severe muscular work during a period of three days, that the increase of nitrogen in the urine apparently lagged a day behind the period of increased muscular exercise, and after the muscular work stopped there was a similar lag in the return of the nitrogen of the urine to the previous level of muscular rest. In this case, however, the data do not exactly define the time of rise and fall of nitrogen secretion or excretion. If the urine had been collected and its nitrogen determined every six hours instead of mixing the amount collected for twenty-four hours together and making but a

[1] Physiologicheskii Sbornik., 1 (1888), p. 56.

single analysis, as was actually done, the results might have given a closer indication of the relation between the times of increased and decreased metabolism and those of increased and decreased excretion of nitrogen.

The experiments here reported were divided into experimental days of twenty-four hours. These experimental days were not calendar days beginning at midnight, but were made to begin at such hours as were most convenient. In experiment No. 4 the nitrogen was collected and examined during twenty-four-hour periods, each beginning and ending six hours after the corresponding experimental day. The arrangements and calculations for experiments 1 and 2 were somewhat different from those for experiments 3 and 4, as explained on page 49.

The principal factors involved in the computation of the nitrogen balance may be stated as follows:

(1) *Nitrogen of food.*—This represents the gross income.

(2) *Nitrogen of feces.*

(3) *Nitrogen of urine.*—This is mainly the nitrogen of compounds from the food and body tissue which have not been completely oxidized, the most important being urea.

Nos. 2 and 3 together make up the gross outgo of nitrogen.

(4) *Nitrogen of food digested and absorbed* and thus made available for use in the body. This is the total nitrogen less that of the feces. Its amount is found by subtracting No. 2 from No. 1. It may be designated as "total available" nitrogen, i. e., the total available for metabolism.

(5) *Nitrogen gained or lost by the body.*—If more nitrogen is taken into the body than is given off—in other words, if No. 1 is greater than the sum of Nos. 2 and 3, or, what is the same thing, if No. 4 is greater than No. 3—the difference will be the amount the body has gained. If, on the other hand, the body has given off more nitrogen than it has received, the difference, No. 3 less No. 4, is the amount lost. It is customary to multiply the amount gained or lost by 6.25 and to assume that the product represents the gain or loss of protein.

CARBON BALANCE.

In like manner the principal data involved in the computation of the carbon balance may be succinctly grouped as follows:

(1) *Carbon of food.*—This is the gross income.

(2) *Carbon of feces.*

(3) *Carbon of urine.*

(4) *Carbon of carbon dioxid exhaled.*

Nos. 2, 3, and 4 together make up the gross outgo.

(5) *Carbon of food digested and absorbed* and thus made available for metabolism. It is found by subtracting No. 2 from No. 1, and may be designated as "total available" carbon, i. e., total available for metabolism. The carbon of the metabolic products of the feces is here treated as if it were a part of the undigested residue of the food.

(6) *Carbon actually utilized.*—This is the carbon absorbed less that excreted by the kidneys in the form of urea and other products of incomplete oxidation of organic compounds. It is found by subtracting No. 3 from No. 5, and may be designated as "net available" carbon, i. e., the total amount available for building tissue or yielding energy.

(7) *Carbon gained or lost by the body.*—If No. 1 is greater than the sum of Nos. 2, 3, and 4, or, what is the same thing, if No. 5 exceeds the sum of Nos. 3 and 4, the difference will represent the gain in carbon. If, on the other hand, the body has lost carbon, the amount will be found by subtracting No. 5 from the sum of Nos. 3 and 4.

GAIN AND LOSS OF PROTEIN AND FAT.

The method usually followed in these computations is the one originally proposed by Pettenkofer and Voit and used by them and other experimenters. It assumes that the nitrogen, carbon, and hydrogen gained or lost by the body belongs to either protein compounds, fats, or carbohydrates, and that these have definite proportions of nitrogen, carbon, and hydrogen. On this basis the quantities of these three elements gained or lost would serve as data for computation ot the gain or loss of each one of the compounds.

Of course these assumptions are not entirely accurate, but they are enough so for our present purpose. Even if they were accurate it would be impossible to tell exactly how much of either class of compounds was actually metabolized and actually stored in the body or resolved into its constituents and given off from the body. It would only be possible to estimate the difference between the total amount of each substance which was stored and the total amount which was broken up and burned. As regards the protein stored or lost, it is impossible to tell how much belongs to either cell tissue or cell contents, or how much has simply formed a part of the blood or other fluids. The case is entirely analogous with the fats and carbohydrates. But it seems fair to assume that the increase or decrease of nitrogenous material will be mainly that of the proteid compounds, which belong properly to connective and contractive tissue, and inasmuch as the proportion of nitrogen in all these is approximately 16 per cent, the quantity of protein gained or lost during the experiment corresponds to very nearly 6.25 times that amount of nitrogen. With the nitrogen of protein is a certain nearly constant amount of carbon. It is easy, therefore, to compute the amount of the latter element which is either stored by the body or lost from the body in protein. The algebraic difference between the protein carbon gained or lost and the total carbon gained or lost represents the carbon gained or lost in carbohydrates and fats. If we had the balance of hydrogen, or, better, the balance of hydrogen and oxygen, and could assume definite quantities of carbon, hydrogen, and oxygen for the carbohydrates and fats, it would be easy to calculate the amounts of these and of water actually gained or lost. It is, however, common to assume that the quantity of carbohydrates in the body, which is very small, is not materially changed, and that consequently the carbon gained or lost outside of that in the protein belongs to fat. Accordingly the gain or loss of carbon outside that belonging to the protein gained or lost is taken as representing the quantity of fat gained or lost. In calculations here used it is assumed that the protein contains 16 per cent of nitrogen and 53 per cent of carbon, and that the fat contains 76.5 per cent of carbon.

The method of computation may be expressed algebraically as follows: Let the amount of gain or loss of nitrogen be represented by $\pm N$ and the amount of gain or loss of carbon by $\pm C$. Then:

$\pm N \times 6.25 =$ protein gained or lost $= \pm P$

$\pm P \times 0.53 =$ carbon gained or lost in protein $= C$ (protein)

$\pm C \mp C$ (protein) $=$ carbon stored or lost as fat $= C$ (fat)

$\pm C$ (fat) $\div 0.765 =$ fat gained or lost.

ENERGY.

The potential energy of the ingredients of food is commonly estimated by the use of the factors proposed by Rubner,[1] which assign 4.1 calories to each gram of protein or carbohydrates and 9.3 calories to each gram of fat. This figure for protein, however, represents a net fuel value, and is obtained by subtracting from the total fuel value of protein, taken as 5.5 calories per gram, the value for the nitrogenous compounds, including urea, not completely oxidized.

In the experiments here described the heats of combustion of the food materials, feces, and dry matter of urine were determined directly by the use of the bomb calorimeter, as above stated. The figures given in the tables, therefore, represent the results of these determinations rather than estimates made by the use of factors. In the computations of energy of the protein and fat gained or lost from the body, however, it is, of course, necessary to use factors. For protein gained or lost the factor 5.5 was employed. For the fat gained or lost the factor 9.4 was used as representing the heat of combustion of human fat per gram.

The principal data involved in these computations may be classified as was done with those of nitrogen and carbon above.

(1) *Total energy of nutrients of food*, or total energy of income. This is represented by the heats of combustion of the food materials.

(2) *Energy in feces*, actual heats of combustion.

(3) *Energy in urine*, heats of combustion of dry matter.

(4) *Total energy in food digested and absorbed.*—This is usually found by subtracting No. 2 from No. 1, and may be designated as *total available* energy. This value obtained by difference, however, does not exactly represent the fuel value realized from the digested food, for the reason that there is always a portion of digested food which is not completely oxidized—namely, the organic matter, mainly nitrogenous, which is secreted by the kidneys and excreted in the urine. Assuming the organism to be in nitrogen equilibrium, the heat of combustion of this partially oxidized material may be assumed to be that of the water-free substance of the urine. For the digestion experiment, in which the gain and loss of body material are left out of account, it is most convenient to estimate the fuel value of this partly oxidized nitrogenous material and subtract it from the total heat of combustion of the digested food. For this purpose it is assumed that the whole will be in the form of urea, and that the amount of the latter will correspond to the amount of digested nitrogen.

(5) *Net energy of food digested and absorbed.*—If protein is neither gained nor lost, the net energy is found by subtracting No. 3 from No. 4. If protein is stored, No. 3 is too small by the value of the urea and kindred compounds corresponding to the nitrogen in the protein stored. If protein is lost, No. 3 is too large by the energy of

[1] Ztschr. Biol., 21 (1885), p. 250.

the urea which comes from the protein lost. The fuel value of urea corresponding to 1 gram of protein is 0.87 calories.[1]

If, then, the protein stored or lost is multiplied by 0.87 and the product added to No. 3 when protein is stored and subtracted from it when lost, the energy of the urine corresponding to the protein digested is obtained. In other words, the net energy of the food digested is No. 4 − (No. 3 $\pm$ 0.87 $\times$ protein gained or lost).

It is extremely probable that further consideration of the subject, together with investigations now contemplated, may lead to more or less change in the details of the method here employed for the estimation of energy of the compounds in question, including especially the nitrogenous compounds. This method will, however, suffice for the present use, which is only tentative.[2]

(6) *Energy liberated as heat or manifested as external muscular work.*—If a balance of energy is to be made, another factor must be taken into account, namely, the heat radiated from the body, and that equivalent to the external muscular work performed. Though this was measured in the present experiment, for the reason already stated, the results are withheld, and the balance of income and outgo of energy is not given.

RESPIRATION EXPERIMENT No. 1 (DIGESTION EXPERIMENT No. 11).

The subject in this experiment was a Swede 29 years of age who acted as laboratory janitor and was accustomed to a moderate amount of muscular work. He would be called a hearty eater. During the progress of the experiments he read a little for diversion, but the larger part of the time was as free from mental and physical activities as practicable. While he was entirely willing to do everything that was required of him, it became evident that he did not find the sojourn in the chamber entirely agreeable. Toward the end of the second experiment he became somewhat ill, but the circumstances were such that it could hardly be attributed to impure air or any other abnormal condition; indeed, there seemed to be good ground to believe that the slight illness was caused by nervousness due to the sojourn in the respiration chamber and an undefined and unfounded fear that some trouble might result.

The diet was comparatively simple. It was of his own selection and was made up of such foods as he would have eaten under ordinary conditions. Three meals a day were eaten. Water was consumed *ad*

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[1] Urea, CON_2H_4, contains 46.67 per cent of nitrogen; consequently N $\times$ 2.143 = urea. From the values obtained by Berthelot, Stohmann, and others, the fuel value of urea may be taken as 2.53 calories per gram. Assuming that all of the digested protein is consumed in the body to urea, we can find the theoretical value of the urea corresponding to 1 gram of protein as follows: Weight of protein $\div$ 6.25 = weight of nitrogen. Weight of N $\times$ 2.143 = weight of urea. Weight of urea $\times$ 2.53 = heat of combustion of urea. Or the heat of combustion of the urea corresponding to 1 gram of protein is $\frac{2.143 \times 2.53}{6.25} = 0.87$ calories. The subject of metabolism of energy is discussed in U. S. Dept. Agr., Office of Experiment Stations Bul. 21, p. 113.

[2] Rubner, Ztschr. Biol., 21 (1885), p. 337. The results of the present experiments, both those given beyond and others still unpublished, agree entirely with Rubner's in showing that the heat of combustion of the dry matter in the urine is much larger than that of the urea, which would correspond to the nitrogen in the urine.

libitum. The foods consumed at each meal are shown in the following table:

TABLE 2.—*Daily menu, respiration experiment No. 1 (digestion experiment No. 11).*

Breakfast.		Dinner.		Supper.	
	Grams.		*Grams.*		*Grams.*
Eggs, about	100	Cooked meat	121	Cheese	75
Butter	15	Butter	20	Milk	600
Milk	100	Milk	300	Milk crackers	100
Bread	100	Bread	150		
Sugar	20	Potatoes	150		
Coffee, about	300				

The digestion experiment was of longer duration than the respiration experiment. It began with breakfast February 15, 1896, and ended with dinner February 19, covering four and two-thirds days and including 14 meals. Of this period two and one-fourth days (11 a. m. February 17 until the close of the experiment) were passed in the respiration chamber. The weight of the subject (without clothing) at the beginning of the latter period was 66.9 kilograms (147½ pounds). The total amount of each food consumed and of the feces excreted during the whole experimental period, the composition and fuel values of food and feces, and the amount and percentage of each nutrient digested are shown in Table 3.

TABLE 3.—*Food eaten and digested during the whole experimental period, 4⅔ days (digestion experiment No. 11).*

Laboratory number.	Kind of food.	Weight for experiment.	Total organic matter.	Protein (N×6.25.)	Fat.	Carbohydrates.	Fuel value, determined.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Calories.*
2696	Beef, fried	604	240	175	59	6	1,506
2695	Eggs, boiled	497	127	64	56		943
4238	Butter	175	153	2	151		1,421
4228	Cheese	300	158	80	74	4	1,266
4227	Milk	4,400	582	159	183	240	3,678
2697	Crackers, milk	396	368	44	48	276	1,852
2693	Bread, rye	1,250	746	115	2	629	3,351
2694	Potatoes, boiled	755	140	17	1	122	594
2722	Sugar	100	100			100	399
	Total		2,607	656	574	1,377	15,010
2764	Feces	102	71	26	15	30	500
	Amount digested		2,536	630	559	1,347	14,510
	Fuel value urea						535
	Net amount digested						13,975
	Per cent digested		97.3	96.1	97.4	97.8	93.1

The amount, composition, and fuel value of the food during the two and one-fourth days (February 17, 11 a. m., to February 19, 5 p. m.) passed in the respiration chamber are shown in the following table:

TABLE 4.—*Food eaten during the period in the respiration chamber, 2¼ days (respiration experiment No. 1).*

Laboratory number.	Kind of food.	Weight per day.	Nitrogen.	Carbon.	Protein (N×6.25.)	Fat.	Carbohydrates.	Fuel values. Determined.	Fuel values. Calculated.
	One day, 3 meals.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Calories.*	*Calories.*
2696	Beef, fried	121	5.61	25.70	35.1	11.8	1.3	302	308
2695	Eggs, boiled	98	2.03	14.16	12.7	11.1		186	181
4238	Butter	35	.05	22.62	.3	30.2		284	283
4228	Cheese	75	3.22	25.07	20.1	18.4	.9	285	285
4227	Milk	1,000	5.80	72.70	36.3	41.5	54.5	836	809
2697	Crackers, milk	100	1.78	44.00	11.1	12.3	69.6	468	461
2693	Bread, rye	250	3.67	64.62	23.0	.4	125.8	670	645
2694	Potatoes, boiled	150	.52	12.00	3.2	.2	24.3	118	119
2722	Sugar	20		8.41			20.0	80	82
	Total		22.68	289.28	141.8	125.9	296.4	3,229	3,173
	For dinner, Feb. 19.								
2696	Beef, fried	120	5.57	25.49	34.8	11.7	1.3	299	306
4238	Butter	20	.03	12.93	.2	17.3		162	162
4227	Milk	300	1.74	21.81	10.9	12.4	16.3	251	243
2693	Bread, rye	150	2.20	38.77	13.8	.2	75.4	402	387
2694	Potatoes, boiled	150	.52	12.00	3.2	.2	24.3	118	119
	Total		10.06	111.00	62.8	41.8	117.3	1,232	1,217
	Grand total, 2¼ days		55.42	689.56	349.2	293.6	710.1	7,690	7,563

On the days which the subject passed in the respiration chamber the urine was collected also. In this and the following experiment it was not collected after the subject left the apparatus.[1] The urine was collected from 6 p. m. on the day before the respiration experiment began to 5 p. m. on the day the experiment ended. As the experiment began at noon, the weights of urine excreted have been recalculated so as to give the weights from noon to noon, instead of from 6 p. m. to 6 p. m. In doing this it was assumed that the amount secreted was uniform from hour to hour, and that the amount for the original period, from 6 p. m. to 6 p. m., could be divided into two parts proportional to the time, one part being the amount from 6 p. m. to 12 m. the next day, the other the amount from 12 m. to 6 p. m. The amount for the short period of six hours, from 12 m. to 6 p. m. of one day, was then added to the amount for the longer period of eighteen hours, from 6 p. m. to 12 m. of the following day, thus giving the total weight for the twenty-four hours from 12 m. to 12 m. Of course, this allows for no lag in the urine (see page 35), but the error thus introduced is probably not very great. The subject had been doing light manual labor before entering the apparatus, and did no work during the experiment. There may have been a slightly larger amount of nitrogen in the urine of the first day of the experiment than was actually metabolized during that day.

[1] In experiments 3 and 4 it was collected for some time after, as stated in the descriptions of those experiments.

Such excess might have been due to the metabolizing of a larger quantity of nitrogen during the day before the subject entered the apparatus. Thus it is to be observed that the weight of nitrogen eliminated in all of the experiments, with the exception of the third, is slightly smaller on the second day than on the first.

The amount of urine and feces excreted while the subject was in the respiration chamber and the nitrogen and carbon content and fuel value of each are given in the following table:

TABLE 5.—*Nitrogen and carbon and fuel value of urine and feces (respiration experiment No. 1).*

Laboratory number.	Urine and feces.	Amount.	Nitrogen.		Carbon.		Fuel value per gram.	Total fuel value.
		Grams.	*Per ct.*	*Grams.*	*Per ct.*	*Grams.*	*Calories.*	*Calories.*
5016	Urine (February 17–18, 12 m. to 12 m.)	1,395	1.45	20.23	0.84	11.72	0.110	154
	Urine (February 18–19, 12 m. to 12 m.)	1,313	1.45	19.04	.84	11.03	.110	145
	Urine (February 19, 12 m. to 5 p. m.)	260	1.45	3.77	.84	2.18	.110	28
	Total	2,968	....	43.04	....	24.93	....	327
2764	Feces (average for 1 day)	21.9	4.14	.91	41.01	8.98	4.903	107
	Total, 2 days	43.8	....	1.82	....	17.96	....	214

The carbon dioxid produced by the subject was measured during the period passed in the respiration chamber. For convenience in collecting samples the day of twenty-four hours was divided into several periods. The volume of air passing through the respiration chamber, the amount of carbon dioxid it contained per liter on entering and on leaving the chamber, and the total amount excreted by the subject, as well as the total amount of carbon in the excreted carbon dioxid are shown in the following table:

TABLE 6.—*Carbon dioxid produced in respiration experiment No. 1.*

Date.	Period.	Ventilation (volume of air).	CO_2 per liter. In incoming air.	CO_2 per liter. In outgoing air.	CO_2 per liter. Given off by subject.	Total weight CO_2 exhaled by subject.	Total weight C exhaled in CO_2.
		Liters.	*Mg.*	*Mg.*	*Mg.*	*Grams.*	*Grams.*
February 17, 12 m., to February 18, 12 m.	12 m. to 7 p. m.	21,724	0.51	12.48	11.97	*a* 60.4 260.0	
	7 p. m. to 2 a. m.	21,094	.61	10.28	9.67	203.9	216.5
	2 a. m. to 9 a. m.	20,566	.59	8.01	7.42	152.7	
	9 a. m. to 3 p. m.	20,052	.58	12.21	11.63	116.6 *b* 116.6	
February 18, 12 m., to February 19, 12 m.	3 p. m. to 10 p. m.	20,300	.58	13.39	12.81	260.4	
	10 p. m. to 4 a. m.	19,450	.58	9.75	9.17	178.4	211.7
	4 a. m. to 11 a. m.	21,227	.60	9.30	8.70	184.7	
February 19, 12 m. to 5 p. m.	11 a. m. to 5 p. m.	17,938	.59	12.74	12.15	36.3 *c* 181.6	49.5

a The air in the respiration chamber at the close of the experiment contained more CO_2 than at the beginning. Analyses of samples, knowing the volume of air in the chamber, showed this difference in amount to be approximately 60.4 grams. It is assumed that this increase took place during the first twenty-four hours, on which assumption 60.4 grams of CO_2 exhaled remained in the apparatus, and hence was not deducted and measured by the regular analyses. Accordingly this amount of CO_2 is added to the amount found by the analysis for the first twenty-four hours.

b Of the period from 9 a. m. to 3 p. m., half belongs to the first and half to the second day of the experiment.

c Of the period from 11 a. m. to 5 p. m., the first hour belongs to the second day and the remainder to the fraction of the third day of the experiment.

From the data of Tables 4, 5, and 6 the balance of income and outgo of carbon and nitrogen is computed with results shown in Table 7.

In this and in the following experiment the subject passed two and one-fourth days (fifty-four hours) in the respiration chamber, and the nitrogen of the urine and the carbon of the carbon dioxid exhaled were determined for this length of time. The number of meals taken, however, was seven, which included two whole days and dinner on the third day. It is, of course, impossible to say how much of the nutrients and energy of the food eaten for dinner at 12 o'clock would be utilized in the body before the close of the experiment at 5 o'clock. There is a similar uncertainty as to how much of the outgo of feces should be accredited to this quarter day. Accordingly, the results of these two experiments have been calculated for the two whole days, the fraction of a day at the close of the experiment being left out of account.

TABLE 7.—*Balance of income and outgo of nitrogen and carbon (respiration experiment No. 1).*

Date.	Nitrogen.				Carbon.					Fuel value.		
	In food.	In urine.	In feces.	Gain.	In food.	In urine.	In feces.	In respiratory products.	Gain.	Of food.	Of urine.	Of feces.
	Gms.	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Calories.*	*Calories.*	*Calories.*
February 17-18, 12 m. to 12 m.	22.7	20.2	0.9	1.6	289.3	11.7	9.0	216.5	52.1	3,229	154	107
February 18-19, 12 m. to 12 m.	22.7	19.0	.9	2.8	289.3	11.0	9.0	211.7	57.6	3,229	145	107
Total, 2 days	45.4	39.2	1.8	4.4	578.6	22.7	18.0	428.2	109.7	6,458	299	214

As explained on p. 38, the amount of protein gained or lost by the body may be computed from the gain or loss of nitrogen, and the amount of fat stored or lost by the body may be computed from the gain or loss of carbon, taking into account also the carbon in the protein gained or lost. The results of such computations are given in the following table:

TABLE 8.—*Gain or loss of protein and fat in respiration experiment No. 1.*

Date.	Nitrogen gained.	Protein gained.	Total carbon gained.	Carbon in protein gained.	Algebraic difference between total carbon and carbon in protein (=M).	Fat gained (M ÷ 0.765).
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
February 17-18, 12 m. to 12 m.	1.6	10.0	52.1	5.3	46.8	61.2
February 18-19, 12 m. to 12 m.	2.8	17.5	57.6	9.3	48.3	63.1
Total, 2 days	4.4	27.5	109.7	14.6	95.1	124.3

The table indicates that during the two days of the experiment 27.5 grams of protein and 124.3 grams of fat were stored up in the body.

RESPIRATION EXPERIMENT No. 2 (DIGESTION EXPERIMENT No. 12).

This experiment was made with the same subject and under the same conditions as experiment No. 1. The digestion experiment began with breakfast February 24, 1896, and ended with dinner February 28, making 14 meals, or four and two-thirds days. The period from 11 a. m., February 26, to the close of the experiment, at 5 p. m., February 28, covering two and one-fourth days, and including 7 meals, was spent in the respiration chamber. The weight of the subject at the beginning of the experiment (without clothing) was 67.5 kilograms (148½ pounds). The daily menu was as follows:

TABLE 9.—*Daily menu, respiration experiment No. 2 (digestion experiment No. 12).*

Breakfast.		Dinner.		Supper.	
	Grams.		*Grams.*		*Grams.*
Eggs, about	100	Cooked meat	121	Cheese	75
Butter	15	Butter	20	Milk	100
Milk	100	Milk	300	Milk crackers	100
Bread	100	Bread	150	Sugar	20
Sugar	20	Potatoes	150	Coffee, about	300
Coffee, about	300				

Tables 10 and 11 show the amounts, composition, and fuel values of the food and feces and the coefficients of digestibility for the whole period (four and two-thirds days) and the amount, composition, and fuel value of the food during the period in the respiration chamber (two and one-fourth days).

TABLE 10.—*Food eaten and digested during the whole experimental period, 4⅔ days (digestion experiment No. 12).*

Laboratory number.	Kind of food.	Weight for experiment.	Total organic matter.	Protein (N×6.25).	Fat.	Carbohydrates.	Fuel value, determined.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Calories.*
2699	Beef, fried	515	217	160	57		1,436
2698	Eggs, boiled	498	127	62	65		1,017
4239	Butter	175	151	2	149		1,432
4237	Cheese	300	169	76	81	12	1,266
4240	Milk	2,400	321	81	108	132	1,973
2701	Crackers, milk	400	368	42	49	277	1,872
2703	Bread, rye	1,136	661	102	2	557	2,961
2700	Potatoes, boiled	661	146	30	1	115	638
2722	Sugar	180	180			180	718
	Total		2,340	555	512	1,273	13,313
2765	Feces	111	81	46	15	20	542
	Amount digested		2,259	509	497	1,253	12,771
	Fuel value urea						448
	Net amount digested						12,323
	Per cent digested		96.5	91.7	97.1	98.4	92.6

TABLE 11.—*Food eaten and digested during the period in the respiration chamber, 2¼ days (respiration experiment No. 2).*

Laboratory number.	Kind of food.	Weight per day.	Nitrogen.	Carbon.	Protein (N×6.25).	Fat.	Carbohydrates.	Fuel values. Determined.	Fuel values. Calculated.
	One day, 3 meals.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Calories.*	*Calories.*
2699	Beef, fried	121	5.87	27.83	36.7	13.4	0.9	337	330
2698	Eggs, boiled	101	2.01	15.10	12.6	13.1	....	206	198
4239	Butter	35	.06	23.24	.3	29.9	....	286	280
4237	Cheese	75	3.05	26.85	19.1	20.3	3.0	317	305
4240	Milk	500	2.70	33.95	16.9	22.5	27.5	411	415
2701	Crackers, milk	100	1.67	44.01	10.4	12.2	68.5	468	452
2703	Bread, rye	228	3.26	58.44	20.4	.5	111.8	594	575
2700	Potatoes, boiled	150	.54	14.31	3.4	.1	29.6	145	141
2722	Sugar	40	....	16.82	....	....	40.0	160	164
	Total	....	19.16	260.55	119.8	112.0	281.3	2,924	2,860
	For dinner, Feb. 28.								
2699	Beef, fried	31	1.50	7.13	9.4	3.4	.2	86	84
4239	Butter	20	.03	13.28	.2	17.1	....	164	160
4240	Milk	300	1.62	20.37	10.1	13.5	16.5	247	249
2703	Bread, rye	80	1.14	20.50	7.2	.2	39.2	208	202
2700	Potatoes, boiled	61	.22	5.82	1.4	....	13.0	59	61
	Total	....	4.51	67.10	28.3	34.2	68.9	764	756
	Grand total, 2¼ days	....	42.83	588.20	267.9	258.2	631.5	6,612	6,476

The amounts of urine and feces excreted during the period in the respiration chamber and the nitrogen and carbon content and fuel value of each are shown in the following table:

TABLE 12.—*Nitrogen and carbon and fuel value of urine and feces (respiration experiment No. 2).*

Laboratory number.	Urine and feces.	Amount.	Nitrogen.		Carbon.		Fuel value per gram.	Total fuel-value.
		Grams.	*Per ct.*	*Grams.*	*Per ct.*	*Grams.*	*Calories.*	*Calories.*
5018	Urine (February 26-27, 12 m. to 12 m.)	969	1.92	18.60	1.52	14.73	0.169	161
	Urine (February 27-28, 12 m. to 12 m.)	913	1.92	17.53	1.52	13.88	.169	154
	Urine (February 28, 12 m. to 5 p. m.)	190	1.92	3.65	1.52	2.89	.169	32
	Total	2,072	....	39.78	....	31.50	....	350
2765	Feces (average for 1 day)	23.8	6.65	1.58	41.49	9.87	4.886	116
	Total, 2 days	47.6	....	3.16	....	19.74	....	232

The carbon dioxid produced during the period in the respiration chamber is shown in the following table:

TABLE 13.—*Carbon dioxid produced in respiration experiment No. 2.*

Date.	Period.	Ventilation (volume of air).	CO_2 per liter. In incoming air.	CO_2 per liter. In outgoing air.	CO_2 per liter. Given off by subject.	Total weight CO_2 exhaled by subject.	Total weight C exhaled in CO_2.
		Liters.	*Mg.*	*Mg.*	*Mg.*	*Grams.*	*Grams.*
February 26, 12 m., to February 27, 12 m.	12 m. to 6 p. m.	21,064	0.56	11.63	11.07	[1]53.2 233.2	227.8
	6 p. m. to 1 a. m.	20,932	.57	11.50	10.93	228.8	
	1 a. m. to 7 a. m.	20,686	.59	8.06	7.47	154.5	
	7 a. m. to 2 p. m.	21,880	.60	11.20	10.60	165.6 [2]66.3	
February 27, 12 m., to February 28, 12m.	2 p. m. to 9 p. m.	22,492	.54	12.65	12.11	272.3	207.3
	9 p. m. to 4 a. m.	22,900	.60	8.45	7.85	179.8	
	4 a. m to 10.30 a. m.	22,216	.61	9.16	8.55	190.0	
February 28, 12 m. to 5 p. m.	10.30 a. m. to 5 p. m.	21,607	.58	10.92	10.34	52.1 [3]171.3	46.8

[1] The air in the respiration chamber at the close of the experiment contained more CO_2 than at the beginning. Analyses of samples, compared with the volume of air in the chamber, showed this difference in amount to be approximately 53.2 grams. It is assumed that this increase took place during the first twenty-four hours, on which assumption 53.2 grams of CO_2 exhaled remained in the apparatus, and hence was not deducted and measured by the regular analyses. Accordingly, this amount of CO_2 is added to the amount found by the analysis for the first twenty-four hours.

[2] Of the period from 7 a. m. to 2 p. m., five hours belong to the first, and the remainder to the second day of the experiment.

[3] Of the period from 10.30 a. m. to 5 p.m., the first one and one-half hours belong to the second day and the remainder to the fraction of the third day of the experiment.

Table 14 shows the balance of income and outgo of nitrogen and carbon. The figures are computed from data given in Tables 11, 12, and 13.

TABLE 14.—*Balance of income and outgo of nitrogen and carbon (respiration experiment No. 2).*

Date.	Nitrogen. In food.	Nitrogen. In urine.	Nitrogen. In feces.	Nitrogen. Gain (+) or loss (—).	Carbon. In food.	Carbon. In urine.	Carbon. In feces.	Carbon. In respiratory products.	Carbon. Gain (+) or loss (—).	Fuel value. Of food.	Fuel value. Of urine.	Fuel value. Of feces.
	Gms.	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Calories.*	*Calories.*	*Calories.*
February 26–27, 12 m. to 12 m.	19.2	18.6	1.6	—1.0	260.6	14.7	9.9	227.8	+ 8.2	2,924	164	116
February 27–28, 12 m. to 12 m.	19.2	17.5	1.6	+0.1	260.6	13.9	9.9	207.3	+29.5	2,924	154	116
Total, 2 days.	38.4	36.1	3.2	—0.9	521.2	28.6	19.8	435.1	+37.7	5,848	318	232

The calculated gains or losses of protein and fat are shown in Table 15.

TABLE 15.—*Gain or loss of protein and fat (respiration experiment No. 2).*

Date.	Nitrogen gained (+) or lost (—).	Protein gained (+) or lost (—).	Total carbon gained.	Carbon in protein gained (+) or lost (—).	Algebraic difference between total carbon and carbon in protein (=M).	Fat gained (M÷0.765).
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
February 26–27, 12 m. to 12 m.	—1.0	—6.3	+ 8.2	—3.3	+11.5	+15.0
February 27–28, 12 m. to 12 m.	+0.1	+0.6	+29.5	+0.3	+29.2	+38.2
Total, 2 days	—0.9	—5.7	+37.7	—3.0	+40.7	+53.2

RESPIRATION EXPERIMENT No. 3 (DIGESTION EXPERIMENT No. 13).

In this experiment the methods had been considerably improved and the force of observers enlarged, advantage being taken of the experience gained in the two previous experiments. The subject was a chemist (O. F. T.) 24 years old. The experiment began with breakfast March 13 and ended with breakfast March 21, 1896, thus covering eight and one-third days and including 25 meals. The respiration experiment proper covered the 5 days with 15 meals from 11 a. m. March 16 to 11 a. m. March 21, inclusive. The weight of the subject at the beginning of the experiment (without clothing) was 57.2 kilograms (126 pounds). The subject was accustomed to rather less muscular labor than the subject of the first two experiments. He was also rather lighter in weight. During the experiment he performed as little muscular labor as possible. He passed the time in resting, with light reading for diversion. The diet, which he himself selected, was somewhat smaller than that of the subject of the first two experiments and furnished considerably less protein and energy.

The daily menu throughout the experiment was as follows:

TABLE 16.—*Daily menu, respiration experiment No. 3 (digestion experiment No. 13).*

Breakfast.		Dinner.		Supper.	
	Grams.		*Grams.*		*Grams.*
Eggs	113	Cooked beef	95	Milk	500
Butter	10	Butter	10	Bread	125
Milk	100	Milk	60	Sugar	10
Bread	75	Bread	75	Peaches or pears	200
Sugar	20	Sugar	20		
Apples	85	Potatoes	130		
Tea or coffee, about	300	Peaches or pears	150		
		Tea or coffee, about	300		

The amounts, composition, and fuel values of the food and feces and the coefficients of digestibility for the whole period (eight and one-third days), and the amount, composition, and fuel value of the food for the period in the respiration chamber (five days) are shown in the following tables:

TABLE 17.—*Food eaten and digested during the whole experimental period, 8⅓ days (digestion experiment No. 13).*

Laboratory number.	Kind of food.	Weight for experiment.	Total organic matter.	Protein (N×6.25).	Fat.	Carbohydrates.	Fuel value, determined.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Calories.*
2704	Beef, fried	766	289	227	62		1,857
2705	Eggs, boiled	904	256	137	119		1,919
4248	Butter	170	152	2	150		1,434
4247	Milk	5,380	717	178	245	294	4,341
2724	Bread	2,275	1,367	187	30	1,150	6,222
2708	Potatoes, boiled	2,300	554	52	3	499	2,373
2709	Apples	755	99	2	1	96	413
2707	Peaches	1,400	146	8	2	136	666
2706	Pears	1,400	277	3	1	273	1,121
2722	Sugar	400	400			400	1,595
	Total		4,257	796	613	2,848	21,941

TABLE 17.—*Food eaten and digested during the whole experimental period, etc.*—Cont'd.

Laboratory number.	Kind of food.	Weight for experiment.	Total organic matter.	Protein (N×6.25).	Fat.	Carbohydrates.	Fuel value, determined.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Calories.*
2760	Feces	131	97	44	20	33	628
	Amount digested		4,160	752	593	2,815	21,313
	Fuel value urea						654
	Net amount digested						20,659
	Per cent digested		97.7	94.5	96.7	98.9	94.2

TABLE 18.—*Food eaten during the period in the respiration chamber, 5 days (respiration experiment No. 3).*

Laboratory number.	Kind of food.	Weight for 5 days.	Nitrogen.	Carbon.	Protein (N×6.25).	Fat.	Carbohydrates.	Fuel values. Determined.	Fuel values. Calculated.
	Five days, 15 meals.								
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Calories.*	*Calories.*
2704	Beef, fried	481	22.75	97.43	142.2	38.7		1,166	1,145
2705	Eggs, boiled	502	12.10	77.46	75.6	66.3		1,066	1,032
4248	Butter	100	.14	67.07	.9	88.4		843	826
4247	Milk	3,300	17.49	203.60	109.2	150.0	180.5	2,663	2,737
2724	Bread	1,375	18.01	355.10	112.9	18.0	695.4	3,760	3,644
2708	Potatoes, boiled	1,350	4.99	130.70	30.5	1.5	293.0	1,393	1,383
2709	Apples	425	.17	23.76	1.0	.7	54.0	232	235
2707	Peaches	700	.63	34.09	5.0	1.3	85.0	333	388
2706	Pears	1,050	.42	85.57	2.2	1.0	170.7	841	718
2722	Sugar	230		96.74			210.0	917	861
	Total		76.70	1,171.52	479.5	365.9	1,688.6	13,214	12,969
	Quantities per day		15.34	234.30	95.9	73.2	337.7	2,643	2,594

Table 19 shows the amounts of urine and feces excreted during the period in the respiration chamber and the nitrogen and carbon content and fuel value of each. In this table a 12-hour lag is allowed in calculating the urine and feces (see p. 35). In the light of the results obtained in the succeeding experiment this seems to be more nearly accurate than the 6-hour lag. The time allowed for lag is, however, probably of comparatively little importance, as the diet and occupation were very nearly uniform.

TABLE 19.—*Nitrogen and carbon and fuel values of urine and feces (respiration experiment No. 3).*

Laboratory number.	Urine and feces.	Amount.	Nitrogen.		Carbon.		Fuel value per gram.	Total fuel value.
		Grams.	*Per ct.*	*Grams.*	*Per ct.*	*Grams.*	*Calories.*	*Calories.*
5020	Urine (March 16–17, 6 a. m. to 6 a. m.)	974	1.30	12.66	0.89	8.66	0.101	98
	Urine (March 17–18, 6 a. m. to 6 a. m.)	1,118	1.20	13.46	.89	9.95	.101	113
	Urine (March 18–19, 6 a. m. to 6 a. m.)	1,188	1.15	13.61	.89	10.57	.101	120
	Urine (March 19–20, 6 a. m. to 6 a. m.)	1,325	1.04	13.69	.89	11.79	.101	134
	Urine (March 20–21, 6 a. m. to 6 a. m.)	1,526	1.00	15.22	.89	13.58	.101	154
	Total	6,131		68.64		54.55		619
2760	Feces (average for 1 day)	16.4	5.34	.87	41.94	6.87	4.796	79
	Total, 5 days	81.9		4.37		34.33		395

The amount of carbon dioxid produced during the period in the respiration chamber is shown in Table 20.

TABLE 20.—*Carbon dioxid produced in respiration experiment No. 3.*

Date.	Period.	Ventilation (volume of air).	CO_2 per liter. In incoming air.	CO_2 per liter. In outgoing air.	CO_2 per liter. Given off by subject.	Total weight CO_2 exhaled by subject.	Total weight C exhaled in CO_2.
		Liters.	*Mg.*	*Mg.*	*Mg.*	*Grams.*	*Grams.*
March 16, 11 a. m., to March 17, 11 a. m.	11 a. m. to 6 p. m.	37,462	0.57	7.57	7.00	262.2	220.9
	6 p. m. to 1 a. m.	41,560	.56	6.13	5.57	231.3	
	1 a. m. to 7 a. m.	37,360	.55	4.61	4.06	151.6	
	7 a. m. to 1 p. m.	36,470	.56	7.19	6.63	[1]164.9 [1]82.6	
March 17, 11 a. m., to March 18, 11 a. m.	1 p. m. to 8 p. m.	40,150	.60	7.21	6.61	265.6	215.3
	8 p. m. to 3 a. m.	29,620	.57	6.86	6.29	186.3	
	3 a. m. to 9 a. m.	27,470	.62	6.88	6.26	171.9	
	9 a. m. to 4 p. m.	31,500	.61	9.89	9.28	[1]83.2 [1]208.2	
March 18, 11 a. m., to March 19, 11 a. m.	4 p. m. to 11 p. m.	30,830	.58	9.07	8.49	261.9	218.8
	11 p. m to 6 a. m.	30,330	.63	5.87	5.24	159.0	
	6 a. m. to 1 p. m.	30,700	.62	8.51	7.89	[1]173.1 [1]69.2	
March 19, 11 a. m., to March 20, 11 a. m.	1 p. m. to 8 p. m.	33,210	.65	8.87	8.22	272.9	222.9
	8 p. m. to 3 a. m.	33,930	.57	6.99	6.42	216.6	
	3 a. m. to 10 a. m.	33,820	.53	7.04	6.51	220.2	
	10 a. m. to 6 p. m.	37,060	.57	8.86	8.29	[1]38.4 [1]268.8	
March 20, 11 a. m., to March 21, 11 a. m.	6 p. m. to 2 a. m.	40,990	.56	7.36	6.80	278.6	221.7
	2 a. m. to 11 a. m.	44,093	.52	6.54	6.02	265.5	

[1] Of the period from 7 a. m. to 1 p. m., March 17, four hours belong to the first and the remainder to the second day of the experiment.

In like manner each experimental period is made to end at 11 a. m., the amount of CO_2 eliminated in the period in which the day ends being divided between that day and the next proportionately to the time.

The balance of income and outgo of nitrogen and carbon, as computed from the data given in Tables 18, 19, and 20, is shown in Table 21:

TABLE 21.—*Balance of income and outgo of nitrogen and carbon (respiration experiment No. 3).*

Date.	Nitrogen. In food.	Nitrogen. In urine.	Nitrogen. In feces.	Nitrogen. Gain (+) or loss (—).	Carbon. In food.	Carbon. In urine.	Carbon. In feces.	Carbon. In respiratory products.	Carbon. Gain (+) or loss (—).	Fuel value. Of food.	Fuel value. Of urine.	Fuel value. Of feces.
	Gms.	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Calories.*	*Calories.*	*Calories.*
March 16–17, 11 a. m. to 11 a. m.	15.3	12.7	0.9	+1.7	234.3	8.7	6.9	220.9	— 2.2	2,645	98	79
March 17–18, 11 a. m. to 11 a. m.	15.3	13.5	.9	+0.9	234.3	9.9	6.9	215.3	+ 2.2	2,645	113	79
March 18–19, 11 a. m. to 11 a. m.	15.3	13.6	.9	+0.8	234.3	10.6	6.9	218.8	— 2.0	2,645	120	79
March 19–20, 11 a. m. to 11 a. m.	15.3	13.7	.9	+0.7	234.3	11.8	6.9	222.9	— 7.3	2,645	134	79
March 20–21, 11 a. m. to 11 a. m.	15.3	15.2	.9	—0.8	234.3	13.6	6.9	221.7	— 7.9	2,645	154	79
Total, 5 days	76.5	68.7	4.5	+3.3	1,171.5	54.6	34.5	1,099.6	—17.2	13,225	619	395

The calculated gains and losses of protein and fat are shown in Table 22:

TABLE 22.—*Gain or loss of protein and fat (respiration experiment No. 3).*

Date.	Nitrogen gained (+) or lost (—).	Protein gained (+) or lost (—).	Total carbon gained (+) or lost (—).	Carbon in protein gained (+) or lost (—).	Algebraic difference between total carbon and carbon in protein (=M).	Fat gained (+) or lost (—) (M÷0.765).
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
March 16-17, 11 a. m. to 11 a. m.	+1.7	+10.6	— 2.2	+ 5.6	— 7.8	—10.2
March 17-18, 11 a. m. to 11 a. m.	+0.9	+ 5.6	+ 2.2	+ 3.0	— 0.8	— 1.0
March 18-19, 11 a. m. to 11 a. m.	+0.8	+ 5.0	— 2.0	+ 2.7	— 4.7	— 6.1
March 19-20, 11 a. m. to 11 a. m.	+0.7	+ 4.4	— 7.3	+ 2.3	— 9.6	—12.6
March 20-21, 11 a. m. to 11 a. m.	—0.8	— 5.0	— 7.9	— 2.7	— 5.2	— 6.8
Total, 5 days	+3.3	+20.6	—17.2	+10.9	—28.1	—36.7

RESPIRATION EXPERIMENT No. 4 (DIGESTION EXPERIMENT No. 14).

The last experiment was more detailed than the previous ones and the observations were more thoroughly systematized. The subject was a physicist (A. W. S.), 22 years old, and weighed (without clothing) at the beginning of the experiment 69.9 kilograms (154 pounds). The experiment began with breakfast March 19 and ended with dinner April 4, thus covering sixteen and two-third days and including fifty meals. During the twelve days beginning 3 p. m. March 23 and ending 3 p. m. April 4 the subject was in the respiration chamber. The twelve days were divided into five periods, the first of one and five-eighths, the fifth of one and three-eighths, and the others of three days' duration each. The first and fifth periods were preliminary and supplementary. In these preliminary and supplementary periods thus reckoned as one the subject did not engage in any muscular or mental work except such reading and very slight physical exercise as were needed to pass away the time comfortably. For convenience in making the calculations of income and outgo, it was assumed that the amounts of ingredients of food and excretory products for the five-eighths and three-eighths days, respectively, made up the corresponding proportions of the total daily amounts. Of course this assumption does not affect the other periods of the experiment. The second period, of three days duration, was devoted to mental labor. The subject engaged for eight hours a day or thereabouts in the active work of either caculating results of previous experiments or studying a German treatise on physics. The mental application was as intense as it could well be made. The third period, likewise of three days' duration, was given to nearly absolute rest. During this time the subject avoided muscular and mental exercise so far as possible. During a larger part of the time he reclined upon the bed. Of course it was impossible to avoid all intellectual activity, but the amount was made as small as practicable. The fourth period was one of intense muscular activity. A pulley was attached to the top of the chamber. Over this passed a cord. One end of the cord was attached to a block of iron weighing 5.7 kilograms (12.5 pounds); on the other end was a handle. This provided for active exercise, not only of the arms, but also of the legs and other parts of the body. The whole arrangement was quite similar to some of the forms of apparatus very commonly used for gymnastic exercise. With this the subject worked severely for eight hours on each of the three days, so that at the end of each day's work he was thoroughly tired. He perspired very freely during the working hours. This period was followed by the final short period of rest.

In examining the detailed results of the experiments it was interesting to note that whatever had been the occupation during the day a period of 6 hours' rest was sufficient to bring the elimination of carbon dioxid back to a normal quantity. Even after the large elimination of carbonic acid which accompanied each period of hard muscular work, amounting at times to 500 grams for six hours, the simple return to rest was followed almost immediately by a return to the normal elimination (see Table 27).

In the case of the elimination of nitrogen in the urine, however, the increase consequent upon hard muscular work or its decrease when the body was in a state of rest did not manifest itself until some hours after the muscular work began or ended (see Table 26). In the calculations for Table 26 a period of six hours was allowed for the lag in the urine. By consulting that table, however, it will be seen that the increase of nitrogen in the urine following the hard work of March 31 did not manifest itself until apparently thirty hours later, and did not cease for an equally long period after the close of active exercise on the evening of April 2, during which time the body had been in a state of as complete inactivity as possible. This subject is referred to beyond.

The character of the food consumed during this experiment is shown in the following daily menu:

TABLE 23.—*Daily menu, respiration experiment No. 4 (digestion experiment No. 14).*

Breakfast.	Grams.	Dinner.	Grams.	Supper.	Grams.
White bread	75	Cooked beef	96	Milk	500
Oatmeal	40	White bread	75	Brown bread	250
Beans	120	Mashed potatoes	100		
Milk	150	Butter	30		
Butter	15	Apples	125		
Sugar	20				

Tables 24 and 25 show the amounts, composition, and fuel values of the food and feces and the coefficients of digestibility for the whole period (sixteen and two-thirds days) and the amount, composition, and fuel value of the food for the period in the respiration chamber (twelve days).

TABLE 24.—*Food eaten and digested during the whole experimental period, 16⅔ days (digestion experiment No. 14).*

Laboratory number.	Kind of food.	Weight for experiment.	Total organic matter.	Protein (N×6.25).	Fat.	Carbohydrates.	Fuel value, determined.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Calories.*
2715	Beef, fried	1,654	738	566	172	....	4,803
4249	Butter	765	673	8	665	....	6,249
4250	Milk	10,600	1,384	351	445	588	8,459
2727	Bread, white	2,550	1,616	235	35	1,346	7,375
2726	Bread, brown	4,000	2,022	232	46	1,744	9,220
2723	Oatmeal	680	609	117	48	444	2,998
2728	Beans	2,040	516	141	7	368	2,405
2725	Potatoes, boiled	1,700	393	42	1	350	1,681
2709	Apples	2,125	279	5	4	270	1,162
2722	Sugar	340	340	....	....	340	1,356
	Total	....	8,570	1,697	1,423	5,450	45,708
2761	Feces	432	330	147	58	125	2,049
	Amount digested	....	8,240	1,550	1,365	5,325	43,659
	Fuel value urea	....	....	....	....	....	1,347
	Net amount digested	....	....	....	....	....	42,312
	Per cent digested	....	96.2	91.3	95.9	97.7	92.6

TABLE 25.—*Food eaten during the period in the respiration chamber, 12 days (respiration experiment No. 4).*

Laboratory number.	Kind of food.	Weight per day.	Nitrogen.	Carbon.	Protein.	Fat.	Carbohydrates.	Fuel values.	
								Determined.	Calculated.
	Twelve days, 36 meals.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Calories.*	*Calories.*
2715	Beef, fried	96	5.28	22.33	33.0	10.0	....	280	273
4249	Butter	45	.08	30.08	.5	39.1	....	368	367
4250	Milk	650	3.45	39.06	21.5	27.3	36.1	519	520
2727	Bread, white	150	2.22	41.73	13.8	2.0	79.2	434	420
2726	Bread, brown	250	2.32	55.67	14.5	2.9	109.0	576	553
2723	Oatmeal	40	1.10	16.46	6.9	2.8	26.1	176	171
2728	Beans	120	1.32	13.64	8.3	.4	21.6	141	138
2725	Potatoes	100	.40	9.77	2.5	.1	20.6	99	99
2709	Apples	125	.05	6.99	.3	.2	15.9	68	69
2722	Sugar	20	....	8.41	....	....	20.0	80	82
	Total	....	16.22	244.14	101.3	84.8	328.5	2,741	2,692

Table 26 gives the amount of urine and feces excreted during the period in the respiration chamber and the nitrogen and carbon content and fuel value of each.

TABLE 26.—*Nitrogen and carbon in urine and feces (respiration experiment No. 4).*

Laboratory number.	Urine and feces.	Amount.	Nitrogen.		Carbon.		Fuel value per gram.	Total fuel value.	Remarks.
		Gms.	*Per cent.*	*Gms.*	*Per cent.*	*Gms.*	*Calories.*	*Calories.*	
5022	Urine (March 23–24, 9 p. m. to 12 m.).	596	1.53	9.12	0.99	5.90	0.113	67	Preliminary period, no work.
	Urine (March 24–25, 12 m. to 12 m.).	772	1.83	14.09	.99	7.64	.113	87	
5023	Urine (March 25–26, 12 m. to 12 m.).	815	1.61	13.12	.72	5.87	.083	68	Mental work.
	Urine (March 26–27, 12 m. to 12 m.).	1,230	1.11	13.71	.72	8.86	.083	102	
	Urine (March 27–28, 12 m. to 12 m.).	1,600	.79	12.64	.72	11.52	.083	133	

TABLE 26.—*Nitrogen and carbon in urine and feces*—Continued.

Laboratory number.	Urine and feces.	Amount.	Nitrogen.		Carbon.		Fuel value per gram.	Total fuel value.	Remarks.
		Gms.	*Per cent.*	*Gms.*	*Per cent.*	*Gms.*	*Calories.*	*Calories.*	
5024	Urine (March 28-29, 12 m. to 12 m.).	1,713	0.70	11.90	0.76	13.02	0.089	152	No work.
	Urine (March 29-30, 12 m. to 12 m.).	1,107	1.12	12.40	.76	8.41	.089	99	
	Urine (March 30-31, 12 m. to 12 m.).	1,422	.92	13.08	.76	10.81	.089	126	
5025	Urine (March 31-April 1, 12 m. to 12 m.).	662	1.77	11.68	1.31	8.67	.151	100	Muscular work.
	Urine (April 1-2, 12 m. to 12 m.) ..	841	1.95	16.40	1.31	11.02	.151	127	
	Urine (April 2-3, 12 m. to 12 m.) ..	798	1.79	14.29	1.31	10.45	.151	121	
5026	Urine (April 3-4, 12 m. to 12 m.) ..	1,529	1.05	16.13	.73	11.16	.055	84	Supplementary period, no work.
	Urine (April 4, 12 m. to 9 p. m.) ..	822	.65	5.34	.73	6.00	.055	45	
	Total	13,907	......	163.90	......	119.33	......	1,311	
2761	Feces (average for 1 day)	25.4	5.46	1.39	41.40	10.52	4.723	120	
	Total	304.8	......	16.64	......	126.20	......	1,440	

The amount of carbon dioxid produced during the period in the respiration chamber is shown in Table 27.

TABLE 27.—*Carbon dioxid produced in respiration experiment No. 4.*

Date.	Period.	Ventilation (volume of air).	CO_2 per liter. In incoming air.	CO_2 per liter. In outgoing air.	CO_2 per liter. Given off by subject.	Total weight CO_2 exhaled by subject.	Total weight C exhaled in CO_2.
		Liters.	*Mg.*	*Mg.*	*Mg.*	*Grams.*	*Grams.*
March 23, 3 p. m., to March 24, 6 a. m.	3 p. m. to 9 p. m.	21,840	0.62	10.48	9.86	214.9	139.2
	9 p. m. to 3 a. m.	23,348	.59	9.42	8.83	206.3	
	3 a. m. to 9 a. m.	23,666	.58	8.12	7.54	[1] 89.3 / [1] 89.3	
March 24, 6 a. m., to March 25, 6 a. m.	9 a. m. to 3 p. m.	20,962	.58	12.76	12.18	255.2	237.0
	3 p. m. to 9 p. m.	21,420	.59	11.89	11.30	242.2	
	9 p. m. to 3 a. m.	22,288	.57	9.05	8.48	189.1	
	3 a. m. to 9 a. m.	21,370	.56	9.29	8.73	[1] 93.2 / [1] 93.3	
March 25, 6 a. m., to March 26, 6 a. m.	9 a. m. to 3 p. m.	21,350	.55	12.77	12.22	260.8	244.3
	3 p. m. to 9 p. m.	21,970	.60	11.96	11.36	249.6	
	9 p. m. to 3 a. m.	21,060	.62	10.34	9.72	204.8	
	3 a. m. to 9 a. m.	21,370	.54	8.71	8.17	[1] 87.3 / [1] 87.3	
March 26, 6 a. m., to March 27, 6 a. m.	9 a. m. to 3 p. m.	21,240	.56	12.28	11.72	248.9	231.6
	3 p. m. to 9 p. m.	22,110	.59	11.44	10.85	239.9	
	9 p. m. to 3 a. m.	20,760	.56	9.47	8.91	184.9	
	3 a. m. to 9 a. m.	21,470	.55	8.76	8.21	[1] 88.2 / [1] 88.1	
March 27, 6 a. m., to March 28, 6 a. m.	9 a. m. to 3 p. m.	20,760	.56	10.96	10.40	215.8	220.7
	3 p. m. to 9 p. m.	21,780	.57	11.05	10.48	228.2	
	9 p. m. to 3 a. m.	22,190	.55	9.05	8.50	188.7	
	3 a. m. to 9 a. m.	21,010	.56	9.01	8.45	[1] 88.8 / [1] 88.8	
March 28, 6 a. m., to March 29, 6 a. m.	9 a. m. to 3 p. m.	20,600	.58	11.32	10.74	221.4	240.6
	3 p. m. to 9 p. m.	21,220	.60	12.52	11.92	252.9	
	9 p. m. to 3 a. m.	21,520	.57	11.31	10.74	231.2	
	3 a. m. to 9 a. m.	20,350	.59	9.23	8.64	[1] 87.9 / [1] 88.0	
March 29, 6 a. m., to March 30, 6 a. m.	9 a. m. to 3 p. m.	20,650	.63	12.30	11.67	240.9	229.4
	3 p. m. to 9 p. m.	21,290	.59	11.60	11.01	234.5	
	9 p. m. to 3 a. m.	20,790	.55	9.51	8.96	186.2	
	3 a. m. to 9 a. m.	20,350	.56	9.57	9.01	[1] 91.7 / [1] 91.7	
March 30, 6 a. m., to March 31, 6 a. m.	9 a. m. to 3 p. m.	21,320	.58	12.20	11.62	247.8	243.2
	3 p. m. to 9 p. m.	21,290	.60	10.72	10.12	215.5	
	9 p. m. to 3 a. m.	21,976	.61	10.88	10.27	225.8	
	3 a. m. to 9 a. m.	20,354	.55	11.45	10.90	[1] 110.9 / [1] 110.9	
March 31, 6 a. m., to April 1, 6 a. m.	9 a. m. to 3 p. m.	21,040	.58	21.09	20.51	431.6	348.0
	3 p. m. to 9 p. m.	21,240	.61	20.37	19.76	419.6	
	9 p. m. to 3 a. m.	20,750	.58	11.20	10.62	220.6	
	3 a. m. to 9 a. m.	20,240	.72	9.94	9.22	[1] 93.3 / [1] 93.4	

[1] Each experimental day ended at 6 a. m.; therefore the amount of CO_2 in the period from 3 a. m. to 9 a. m. is divided equally between the two days.

TABLE 27.—*Carbon dioxid produced in respiration experiment No. 4*—Continued.

Date.	Period.	Ventilation (volume of air).	CO_2 per liter. In incoming air.	CO_2 per liter. In outgoing air.	CO_2 per liter. Given off by subject.	Total weight CO_2 exhaled by subject.	Total weight C exhaled in CO_2.
		Liters.	*Mg.*	*Mg.*	*Mg.*	*Grams.*	*Grams.*
April 1, 6 a. m., to April 2, 6 a. m.	9 a. m. to 3 p. m....	21,290	0.65	24.18	23.53	500.9	384.7
	3 p. m. to 9 p. m....	21,330	.63	22.73	22.10	471.4	
	9 p. m. to 3 a. m....	20,890	.62	11.36	10.74	246.0	
	3 a. m. to 9. a. m....	19,390	.71	10.94	10.23	[1]99.1 [1]99.2	
April 2, 6 a. m., to April 3, 6 a. m.	9 a. m. to 3 p. m....	19,972	.61	23.92	23.31	465.6	381.7
	3 p. m. to 9 p. m....	21,400	.65	24.62	23.97	512.9	
	9 p. m. to 3 a. m....	21,941	.83	11.39	10.56	231.6	
	3 a. m. to 9 a. m....	20,820	1.55	10.27	8.72	[1]90.8 [1]90.8	
April 3, 6 a. m., to April 4, 6 a. m.	9 a. m. to 3 p. m....	20,686	.83	11.86	11.03	228.2	242.7
	3 p. m. to 9 p. m....	21,360	.87	13.40	12.53	266.8	
	9 p. m. to 3 a. m....	21,125	1.23	11.29	10.06	212.4	
April 4, 6 a. m., to April 4, 3 p. m.	3 a. m. to 9 a. m....	20,575	1.94	10.86	8.92	[1]91.8 [1]91.8	93.9
	9 a. m. to 3 p. m....	21,268	.57	12.44	11.87	252.5	

[1] Each experimental day ended at 6 a. m.; therefore the amount of CO_2 in the period from 3 a. m. to 9 a. m. is divided equally between the two days.

The balance of income and outgo of nitrogen and carbon made up from data given in Tables 25, 26, and 27 is shown in the following table:

TABLE 28.—*Balance of income and outgo of nitrogen and carbon (respiration experiment No. 4).*

Date.	Nitrogen. In food.	Nitrogen. In urine.	Nitrogen. In feces.	Nitrogen. Gain (+) or loss (—).	Carbon. In food.	Carbon. In urine.	Carbon. In feces.	Carbon. In respiratory products.	Carbon. Gain (+) or loss (—).	Fuel value. Of food.	Fuel value. Of urine.	Fuel value. Of feces.
	Gms.	*Gms.*	*Gms.*	*Gms.*	*Grams.*	*Gms.*	*Gms.*	*Grams.*	*Grams.*	*Calories.*	*Calories.*	*Calories.*
March 23–24, 9 p. m. to 12 m...	10.1	9.1	0.9	+0.1	152.6	5.9	6.6	139.2	+ 0.9	1,713	67	75
March 24–25, 12 m. to 12 m.....	16.2	14.1	1.4	+0.7	244.1	7.6	10 5	237.0	— 11.0	2,741	87	120
March 25–26, 12 m. to 12 m.....	16.2	13.1	1.4	+1.7	244.1	5.9	10.5	244.3	— 16.6	2,741	68	120
March 26–27, 12 m. to 12 m.....	16.2	13.7	1.4	+1.1	244.1	8.9	10.5	231.6	— 6.9	2,741	102	120
March 27–28, 12 m. to 12 m.....	16.2	12.6	1.4	+2.2	244.1	11.5	10.5	220.7	+ 1.4	2,741	133	120
March 28–29, 12 m. to 12 m.....	16.2	11.9	1.4	+2.9	244.1	13.0	10.5	240.6	— 20.0	2,741	152	120
March 29–30, 12 m. to 12 m.....	16.2	12.4	1.4	+2.4	244.1	8.4	10.5	229.4	— 4.2	2,741	99	120
March 30–31, 12 m. to 12 m.....	16.2	13.1	1.4	+1.7	244.1	10.8	10.5	243.2	— 20.4	2,741	126	120
March 31–April 1, 12 m. to 12 m	16.2	11.7	1.4	+3.1	244.1	8.7	10.5	348.0	—123.1	2,741	100	120
April 1–2, 12 m. to 12 m........	16.2	16.4	1.4	—1.6	244.1	11.0	10.5	384.8	—162.2	2,741	127	120
April 2–3, 12 m. to 12 m...	16.2	14.3	1.4	+0.5	244.1	10.4	10.5	381.8	—158.6	2,741	121	120
April 3–4, 12 m. to 12 m........	16.2	16.1	1.4	—1.3	244.1	11.2	10.5	242.7	— 20.3	2,741	84	120
April 4, 12 m. to 9 p. m.........	6.1	5.4	.5	+0.2	91.5	6.0	3.9	93.9	— 12.3	1,028	45	45
Total, 12 days	194.4	163.9	16.8	+13.7	2,929.2	119.3	126.0	3,237.2	—553.3	32,892	1,311	1,440

The calculated gains and losses of protein and fat are shown in the following table:

TABLE 29.—*Gain or loss of protein and fat (respiration experiment No. 4).*

Date.	Nitrogen gained (+) or lost (—).	Protein gained (+) or lost (—).	Total carbon gained (+) or lost (—).	Carbon in protein gained (+) or lost (—).	Algebraic difference between total carbon and carbon in protein (=M).	Fat gained (+) or lost (—) (M ÷ 0.765).
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
March 23-24, 9 p. m. to 12 m.	+0.1	+ 0.6	+ 0.9	+ 0.3	+ 0.6	+ 0.8
March 24-25, 12 m. to 12 m.	+0.7	+ 4.4	— 11.0	+ 2.3	— 13.3	— 17.4
March 25-26, 12 m. to 12 m.	+1.7	+10.6	— 16.6	+ 5.6	— 22.2	— 29.0
March 26-27, 12 m. to 12 m.	+1.1	+ 6.9	— 6.9	+ 3.7	— 10.6	— 13.8
March 27-28, 12 m. to 12 m.	+2.2	+13.8	+ 1.4	+ 7.3	— 5.9	— 7.7
March 28-29, 12 m. to 12 m.	+2.9	+18.1	— 20.0	+ 9.6	— 29.6	— 38.7
March 29-30, 12 m. to 12 m.	+2.4	+15.0	— 4.2	+ 8.0	— 12.2	— 15.9
March 30-31, 12 m. to 12 m.	+1.7	+10.6	— 20.4	+ 5.6	— 26.0	— 34.0
March 31-April 1, 12 m. to 12 m.	+3.1	+19.4	—123.1	+10.3	—133.4	—174.4
April 1-2, 12 m. to 12 m.	—1.6	—10.0	—162.2	— 5.3	—156.9	—205.1
April 2-3, 12 m. to 12 m.	+0.5	+ 3.1	—158.6	+ 1.6	—160.2	—209.4
April 3-4, 12 m. to 12 m.	—1.3	— 8.1	— 20.3	— 4.3	— 16.0	— 20.9
April 4, 12 m. to 9 p. m.	+0.2	+ 1.2	— 12.3	+ 0.6	— 12.9	— 16.9
Total, 12 days	+13.7	+85.6	—553.3	+45.3	—598.6	—782.4

DISCUSSION OF RESULTS.

VENTILATION AND PRODUCTION OF CARBON DIOXID.

The observations regarding ventilation and the effects of the presence of carbonic acid in large quantities are of decided interest. The incoming air, which was ordinary fresh air from the outside of the building, contained on the average from 0.5 to 0.6 of a milligram of carbon dioxid per liter; in the outgoing air the amount of carbon dioxid averaged about 11 milligrams per liter, though the variations from this amount were considerable. In the last experiment, especially, the differences in bodily activity in the different periods were very large, and the differences in carbon dioxid exhalation were correspondingly great. The results are epitomized in Table 30, which shows the quantities of air supplied and carbon dioxid produced in each of the four experiments:

TABLE 30.—*Amount of carbon dioxid produced in the respiration apparatus.*

Experiment number.	Subject.	Occupation.	Duration of experiment.	Air supplied per minute.	Amounts of CO_2 per liter in outgoing air. Minimum.	Maximum.	Average.	Average amount of CO_2 given off in 24 hours.
			Days.	*Liters.*	*Mg.*	*Mg.*	*Mg.*	*Grams.*
1	Janitor (E. O.)	Rest	$2\frac{1}{4}$	49	8.0	13.4	11.0	778.6
2	do	do	$2\frac{1}{4}$	50	8.1	12.7	10.4	794.6
3	Chemist (O. F. T.)	Light mental work.	5	75	4.6	9.9	7.4	806.4
4	Physicist (A. W. S.)	Rest	$1\frac{5}{8}$	55	8.1	12.8	10.2	848.9
		Mental work	3	55	8.7	12.8	10.5	851.5
		Rest	3	55	9.0	12.5	10.9	871.7
		Muscular work	3	55	[illegible]9	24.6	16.9	1,362.3
		Rest	$1\frac{3}{8}$	55	10.9	13.4	11.8	897.7
	Average, 12 days		12	55	8.1	24.6	12.1	989.2

The table shows that the quantity of carbon dioxid in the incoming air was normal, ranging from 0.55 to 0.60 milligrams per liter. The ventilation in experiments Nos. 1 and 2 was at the rate of about 50 liters of air per minute; the carbon dioxid in the outgoing air varied from 8 to 13.4 and averaged 10.7 milligrams per liter.

In experiment No. 3, with an average ventilation of 75 liters of air per minute, the range of carbon dioxid in the air was from 4.6 to 9.9 milligrams per liter and the average 7.4 milligrams per liter. The smaller quantity of carbon dioxid in the air as compared with experiments Nos. 1 and 2 was due to the larger ventilation, since the average weight of carbon dioxid given off in twenty-four hours was 848.9 grams as compared with 778.6 grams in experiment No. 1 and 794.6 in experiment No. 2. In these experiments the subject was either at rest or engaged in light mental work or reading.

Experiment No. 4 is of much more interest in this connection, since the differences in mental and physical exercise were much wider. During the first and fifth periods of one and five-eighths and one and three-eighths days, respectively, the subject was at rest. During the second period, which lasted three days, he was engaged in rather severe mental work. The third period was one of as nearly absolute rest as was practicable. In the fourth period the subject was engaged in severe muscular work for eight hours per day. The rate of ventilation was 55 liters per minute. The temperature of the air in the chamber was generally from 19° to 20° C., though it fell at times to 17° and rose during the periods of hard muscular work to 22°.

The weight of carbon dioxid given off in twenty-four hours ranged from about 850 to 900 grams for the days at rest and was no larger with mental work, but averaged over 1,360 grams for the days of muscular work. During two periods of six hours each of hard muscular work the elimination of carbon dioxid reached 513 and 501 grams, respectively. During the night, or sleeping period, the exhalation of carbon dioxid was singularly constant irrespective of the day's occupation. It amounted to 175 grams in six hours, with but slight variation from that figure.[1]

The weight of carbon dioxid in the outgoing air during the periods of rest and mental work ranged from 8.1 to 13.4 milligrams per liter, but averaged not far from 11 milligrams per liter. During the period of muscular work, however, the range was from 9.9 milligrams per liter in the hours of rest, e. g., at night, to 24.6 milligrams per liter in the hours of severe work.

Authorities on ventilation commonly estimate the maximum of carbon dioxid permissible in the air of inhabited rooms at one part per thousand by volume, which corresponds to about 1.97 milligrams of carbon dioxid

[1]For recent observations of the variations in the amount of carbon dioxid excreted during sleeping and waking and under various conditions of work and rest, see investigations by Sondén and Tigerstedt (Skand. Arch. Physiol., 6 (1895), Nos. 1-3, pp. 1-224; abstracted in Experiment Station Record 8, p. 242).

per liter. It will be observed that the amounts of carbon dioxid in the air in the respiration chamber during these experiments was from 8 to 25 milligrams per liter, and averaged 10 to 12 milligrams per liter. In other words, the subjects of these experiments lived constantly in an atmosphere containing from five to six times the amount of carbon dioxid in the standard just referred to. In experiment No. 4 the carbon dioxid rose to nearly thirteen times the amount in the standard.

The interesting fact in this connection is that no one of the subjects appeared to experience any inconvenience whatever from either these large amounts of carbon dioxid or from any other products of exhalation.

The subject who remained in the apparatus during the five days of the third experiment was as comfortable in every way, according to his repeated statements both during the experiment and afterwards, as if he had been in a room supplied with a larger amount of air. Even in the fourth experiment the subject was not aware of the least inconvenience or discomfort during the twelve days of his sojourn in the chamber.

It may be added that these results are in accord with the late experiments by Billings, Mitchell, and Bergey,[1] which imply that the discomfort experienced in poorly ventilated rooms is not due to the excess of carbon dioxid. It seems probable, however, that one cause of the discomfort felt in badly ventilated rooms occupied by a number of people may be the large amount of moisture which accumulates in the air, while at the same time the temperature rises. Some of the observations made in the experiments above described accord with this hypothesis.[2]

In anticipation of a special treatment of this phase of the experiments in another place, further discussion is omitted here.

NUTRIENTS AND FUEL VALUES.

The nutrients and fuel values of the food eaten and digested in the four experiments are briefly summarized in the following table:

TABLE 31.—*Total and digested nutrients and fuel value of daily food in the four respiration experiments.*

Experiment number.	Subject.	Duration of experiment.	In total food.				In digested food.			
			Protein.	Fat.	Carbohydrates.	Fuel value, determined.	Protein.	Fat.	Carbohydrates.	Fuel value, determined.*a*
		Days.	*Grams.*	*Grams.*	*Grams.*	*Calories.*	*Grams.*	*Grams.*	*Grams.*	*Calories.*
1	Janitor (E. O.)	2¼	142	126	296	3,230	136	123	290	2,970
2	....do	2¼	120	112	281	2,925	110	109	277	2,650
3	Chemist (O. F. T.)	5	96	73	338	2,645	90	69	331	2,460
4	Physicist (A. W. S.)	12	101	85	329	2,740	93	62	321	2,510

a Fuel value of total food less that of feces and urine.

[1] On the composition of expired air and its effect on animal life. Smithsonian Contributions to Knowledge, Vol. XXIX (No. 989, Hodgkins fund).

[2] Defren (Tech. Quart., 9 (1896), No. 2–3, p. 238; E. S. R., 8, p. 385) has suggested that the deleterious effect of badly ventilated rooms may be due to the presence of nitrites, which he has found in considerable quantities in the air of such rooms.

The balance of income and outgo of nitrogen and carbon and the gain or loss of body protein and fat in the four experiments are briefly summarized as follows:

TABLE 32.—*Balance of income and outgo of nitrogen and carbon and gain or loss of body protein and fat in the four respiration experiments.*

Respiration experiment number.	Subject.	Occupation.	Duration of experiment.	Nitrogen.				Carbon.					Protein.	Fat.
				In food.	In urine.	In feces.	Gain (+) or loss (—).	In food.	In urine.	In feces.	In respiratory products.	Gain (+) or loss (—).	Gain (+) or loss (—).	Gain (+) or loss (—).
			Days.	*Gms.*	*Gms.*	*Gs.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*
1	Janitor (E. O.).	Rest....	2	45.4	39.2	1.8	+ 4.4	578.6	22.7	18.0	428.2	+109.7	+27.5	+124.3
2	....do	....do...	2	38.4	36.1	3.2	— 0.9	521.2	28.6	19.8	435.1	+ 37.7	— 5.7	+ 53.2
3	Chemist (O.F.T.).	Light mental work.	5	76.5	68.7	4.5	+ 3.3	1,171.5	54.6	34.5	1,099.6	— 17.2	+20.6	— 36.7
4	Physicist (A.W.S.).	Rest....	$1\frac{5}{8}$	26.3	23.2	2.3	+ 0.8	396.7	13.5	17.1	376.2	— 10.1	+ 5.0	— 16.6
		Mental work.	3	48.6	39.4	4.2	+ 5.0	732.3	26.3	31.5	696.6	— 22.1	+31.3	— 50.5
		Rest....	3	48.6	37.4	4.2	+ 7.0	732.3	32.2	31.5	713.2	— 44.6	+43.7	— 88.6
		Muscular w'k.	3	48.6	42.4	4.2	+ 2.0	732[illegible]	30.1	31.5	1,114.6	—443.9	+12.5	—588.9
		Rest....	$1\frac{3}{8}$	22.3	21.5	1.9	— 1.1	335.6	17.2	14.4	336.6	— 32.6	— 6.9	— 37.8
		Whole exp't.	12	194.4	163.9	16.8	+13.7	2,929.2	119.3	126.0	3,237.2	—555.3	+85.6	—782.4

As explained previously, the total income is represented by the food actually eaten (with drink and the oxygen of inhaled air), and the net income by the total income minus the outgo in the feces, taking into account also the incompletely oxidized material excreted in the urine. The net income represents that part of the food which is available for the body. If the amount available is just sufficient for the needs of the organism it will all be burned in the body to yield energy. If it is insufficient some of the body tissue will be burned also, and if it is more than sufficient some material may be stored. The nitrogen in the urine is assumed to represent the nitrogenous material which has been (incompletely) burned in the body. In the present experiments it is assumed that the carbon in the urine is from the same source. The carbon of the respiratory products is taken as representing the carbon which has been completely burned.

In Table 33 are shown the nitrogen, carbon, and energy in the daily net income and the material actually burned in the body in the four experiments.

TABLE 33.—*Daily net income and material actually burned in the body in the four experiments.*

Experiment number.	Subject.	Occupation.	Duration of experiment.	Digested food.			Material burned in the body.		
				Nitrogen.	Carbon.	Fuel value.	Nitrogen. *a*	Carbon. *b*	Fuel value.
			Days.	*Grams.*	*Grams.*	*Calories.*	*Grams.*	*Grams.*	*Calories.*
1	Janitor (E. O.)....	Rest..........	2	21.8	280.3	2,970	19.6	225.5	2,310
2	....do..............	.....do........	2	17.6	250.7	2,650	18.0	231.8	2,420
3	Chemist (O. F. T.).	Light mental work.	5	14.4	227.4	2,460	13.7	230.9	2,505
4	Physicist (A. W. S.).	Rest..........	$1\frac{5}{8}$	14.8	233.6	2,525	14.3	238.4	2,585
		Mental work..	3	14.8	233.6	2,520	13.1	241.0	2,620
		Rest..........	3	14.8	233.6	2,495	12.5	248.4	2,695
		Muscular work	3	14.8	233.6	2,505	14.1	381.6	4,325
		Rest..........	$1\frac{3}{8}$	14.8	233.6	2,540	15.2	260.2	2,875
	Av. for 12 days...	....	......	14.8	233.6	2,510	13.6	279.7	3,085

a Nitrogen of urine, i. e., of incompletely oxidized nitrogenous material of food and body.
b Carbon of respiratory products plus that of urine.

In the first experiment the amount of protein was rather large. The subject, a laboratory janitor, was accustomed to somewhat active muscular work and had a very hearty appetite. The diet was of his own selection and proved more than sufficient for the needs of his organism during the experiment when he was comparatively inactive. His organism stored both protein and fat.

In the next experiment, which was made with the same person, the diet was the same in kind, but less in quantity. The ration proved insufficient to maintain the nitrogen equilibrium, although some fat was stored. In this case, however, the quantities of protein lost and of fat gained were quite small, so that the organism was very nearly in equilibrium, especially as regards nitrogen.

In the third experiment the diet was considerably smaller in protein and energy than in the two preceding. The subject, a chemist, was accustomed to rather less muscular labor than the subject of the first and second experiments. He was also rather lighter in weight. The diet which he chose was smaller in both nutrients and energy. The figures indicate a slight gain of protein and loss of fat during the experiment, but on the whole the organism was very nearly in equilibrium in respect to both nitrogen and carbon. The fuel value of the material actually consumed in the body was larger than in either of the two preceding experiments, though somewhat smaller than that in the fourth experiment under similar conditions.

In the fourth experiment the subject was a physicist. He was taller than the subject of the third and heavier than either of the subjects in the preceding experiments. The diet was of his own selection, as in the previous cases. The amount of nitrogen was less than in the first two experiments, though slightly more than in the third. The potential energy of the digested food was a little larger than in that of the third experiment. Nevertheless, the figures indicate a slight gain rather than loss of protein during all of the periods of the experiment when there was no especially great muscular activity, though there was constant loss of fat from the organism. In the period of muscular activity the loss of fat was very much larger, the loss of carbon being 148 grams per day.

In discussing the gain or loss of protein the nitrogen lag is an important factor. It has been stated above that in experiment No. 4 an allowance of six hours was made for the lag of the urine. That this time was insufficient was also pointed out, and thirty hours was suggested as probably more nearly representing the period of lag. Table 34 gives the nitrogen and carbon in the net income and outgo for the three important periods of this experiment, with the calculated nitrogen and carbon actually burned in the body and energy liberated, allowing for both six hours' lag and thirty hours' lag.

TABLE 34.—*Daily net income and material actually burned in the body, allowing for 6 hours' and 30 hours' lag of urine.*

	Length of period.	Nitrogen.			Protein gain (+) or loss (—).	Carbon.			Fat loss.	Fuel-value loss.
		In digested food.	In material burned in the body.	Gain (+) or loss (—).		In digested food.	In material burned in the body.	Loss.		
Allowing 6 hours' lag:	*Days.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Calories.*
Mental work....	3	14.8	13.1	+1.7	+10.4	233.6	241.0	— 7.4	— 16.8	— 100
Rest............	3	14.8	12.5	+2.3	+14.6	233.6	248.4	— 14.8	— 29.5	— 200
Muscular work	3	14.8	14.1	+0.7	+14.2	233.6	381.5	—147.9	—196.3	—1,820
Allowing 30 hours' lag:										
Mental work....	3	14.8	12.7	+2.1	+13.0	233.6	243.3	— 9.7	— 21.7	— 135
Rest............	3	14.8	12.4	+2.4	+15.0	233.6	247.0	— 13.4	— 27.8	— 180
Muscular work.	3	14.8	15.6	—0.8	— 5.0	233.6	382.4	—148.8	—191.0	—1,825

When the nitrogen lag is assumed to be six hours there is a small gain of protein during the period of muscular work; but when it is assumed to be thirty hours there is a small loss. When a thirty-hour nitrogen lag is assumed the gains in protein during the periods of rest and mental labor are somewhat larger than when a six-hour lag is assumed.

It will be noticed that there are marked differences in the ways the subjects in the four experiments utilized the food material at their disposal. The differences in age, weight, occupation, and diet have been referred to. It will, however, be of interest to add that some studies had been previously made which throw a little more light upon the dietary habits of two of them.

Two dietary studies were made in the family of the laboratory janitor, one in February and the other in March, 1894.[1] In these the average protein in the food eaten per man per day was estimated at 126 grams,

[1] See Report of Storrs (Conn.) Agricultural Experiment Station, 1894, pp. 180 and 195.

and the total energy of the nutrients at 3,900 calories. The corresponding amounts digested were estimated at approximately 116 grams of protein and 3,660 calories. This was, on the whole, a liberal diet. It is slightly larger than the American standard[1] suggested for a man at moderately severe muscular work.

Two dietary studies were made by the subject of experiment No. 4 at his home in a country town in another State, on the occasions of vacation visits, one in the winter and the other in summer.[2] There was but little difference between the results of the two. It seems fair to assume that they may represent the dietary habits which the subject had naturally acquired. The averages per man per day were approximately 79 grams of protein and 3,125 calories of energy. These quantities are estimated to correspond to about 71 grams of protein and 2,955 calories of energy in the food actually digested.

It will be observed that, according to the above estimates, the laboratory janitor, who was accustomed to moderately active muscular work ten hours per day, and who was what would be called a "hearty eater," actually burned during the first experiment 122 grams of the 136 grams of digestible protein in his food and at the same time stored the remaining 14 grams, according to the calculations of these experiments. Of the 2,970 calories in the food digested he burned material corresponding to 2,310 calories. The digested nutrients of the food furnished an excess of carbohydrates and fats as well as protein, so that his organism stored fat and protein corresponding to 660 calories of energy. In the second experiment his diet was reduced so as to supply only 110 grams of digestible protein and 2,650 calories of energy. In this case his organism was estimated to burn 113 grams of protein, a trifle more than the food supplied, and 2,420 calories of energy. The organism gained considerable fat, enough to make a gain of material corresponding to 230 calories of energy.

The subjects of experiments Nos. 3 and 4, who were accustomed to only light muscular activity, chose for their diet materials computed to supply 90 and 93 grams of digestible protein, respectively, and other digestible nutrients sufficient to furnish about 2,500 calories of energy per day. In the respiration apparatus when at rest or engaged in either light or severe mental work they burned in the body from 78 to 86 grams of protein and from about 2,500 to 2,700 calories of energy. It was evident that this consumption must have been reasonably economical, since the food in experiment No. 3 supplied only a trifle more protein and a trifle less energy than was utilized; while in experiment No. 4, when the subject was at rest or engaged in mental work there was with a slight apparent gain of protein a decided loss of fat. Although the subject of experiment No. 4 was a man of larger frame and greater weight than the subject of experiment No. 3, his organism

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 21, p. 213.

[2] See Reports of Storrs (Conn.) Experiment Station, 1895, p. 137, and 1896, p. 144.

burned less protein; but this seems to accord with the results of dietary studies mentioned above, which implies that he was in the habit of consuming small quantities of protein. While his organism burned smaller quantities of protein, it burned more fat and utilized more energy than was the case with the subject of experiment No. 3. When the same person engaged in severe muscular work the amount of protein burned rose from 78 to 98 grams per day. At the same time the energy utilized rose from 2,695 to 4,325 calories. That there should be such an increase in the amount of both protein burned and energy utilized with the severe muscular work is not at all surprising. How the amount of protein burned during the period of muscular work would have been affected if the quantity of carbohydrates and fats had been sufficient to supply the needed energy is a question to be answered by further experiment.

CONCLUSIONS.

The experiments above described offer considerable material for discussion. Since, however, they are of a preliminary character and are to be followed by others in which the results of the experience here obtained will be used, it is deemed best to reserve the discussion until more of the anticipated work shall have been accomplished. Meanwhile the following statements are perhaps in place:

(1) The experience here obtained emphasizes the desirability of longer experimental periods than have been customary in experiments of this class. Although a considerable number of respiration experiments have been made with animals and man, the periods have rarely exceeded twenty-four hours. The figures in the tables above are sufficient to show that the results obtained in periods so short are less conclusive than is to be desired.

(2) Much care needs to be bestowed upon the analyses of the materials of income and outgo. In the majority of experiments thus far reported the composition of food and solid and liquid excretory products has been in large part assumed, rather than estimated from direct analyses of specimens of the materials belonging to the experiments. In like manner there is need of the greatest possible care and accuracy in the determination of the gaseous excretory products. Nor can any of the organic matters given off in perspiration and exhalation be left out of account if the fullest accuracy is to be attained.

(3) It is to be hoped that future experience may lead to such improvements as shall insure the accurate measurement of all the chemical elements involved in the income and outgo. It is evident that there are no insurmountable obstacles in the way of reasonably accurate estimation of the income and outgo of nitrogen and carbon. As regards the hydrogen, the difficulties of determination have thus far been more serious, but they do not appear to be by any means insurmountable. The quantities of sulphur and phosphorus are so small that extreme accuracy is needed for their estimation in order to insure

satisfactory comparison of income and outgo. The experience gained in this laboratory since the experiments here described were made indicates that by refinement of methods reasonably reliable results may be obtained.

(4) The prospects for obtaining a satisfactory balance of income and outgo of energy are, on the whole, decidedly encouraging. The determinations of heats of combustion by the bomb calorimeter are eminently satisfactory, and there seems to be good ground to hope that ultimately the measurements of heat given off from the body may also prove sufficiently accurate for such purposes. Satisfactory results have already been reported by other experimenters with small animals and with men during experiments of short duration. Experience in this laboratory since the above experiments were made have yielded results agreeing very closely indeed with the theoretical figures.

(5) The results of these experiments and of similar investigations elsewhere bring out very clearly the difference in the amounts of nutrients and energy required by the organisms of different persons under different conditions, and confirm the results of previous inquiry in showing that muscular labor is performed at the expense of the fats, sugars, and starches. They also make it clear that the body may draw upon protein for this purpose, although it has not yet been determined just what are the conditions under which this is done. A large amount of work will be needed to secure the experimental data necessary for accurate generalizations. The importance of the subject is such as to call for the most extensive and painstaking research.