THE RESPIRATION CALORIMETER.

By W. O. Atwater, Chief, and F. G. Benedict, Physiological Chemist, Nutrition Investigations, Office of Experiment Stations.

STUDIES OF THE DEMANDS OF THE HUMAN BODY.

In considering the demands of the body for nourishment and the purposes which foods serve in the body, it was natural that experimenters should direct their attention for a time largely to those questions which were most readily studied, such as the amounts of food eaten and their relation to growth, health, and other physical conditions. The chemical composition of different foods and the purpose served by different food constituents are closely related to such studies. The amount and character of the visible excretory products and the relation of the body outgo to the food eaten were questions whose importance was early recognized. Knowing the amount and composition of the food and the amount and composition of the solid outgo, it is possible to ascertain how thoroughly food is digested, and experiments to determine this point have been numerous and have given very valuable results. In tests of the adequacy of a diet and other problems equally important it is desirable to study also the amount and composition of the liquid outgo.

Besides the visible excreta, however, the body is constantly giving off invisible material in the breath. A knowledge of the kind and amount of these invisible products and their relation to food, to work performed, and to other factors, is a matter whose importance was early recognized and studied in various more or less satisfactory ways. Moreover, in addition to all the material products—visible and invisible—the body is all the time losing an immaterial invisible quantity, namely, the heat which is constantly radiated from its surface. We know that in order for heat to be given off from a stove or furnace a supply of fuel must be kept up, and it is obvious that something of the same nature must be true in the case of the human body. In the one case the fuel is coal, wood, or some similar substance; and in the other it is meat, vegetables, cereals, and other foods which make up the daily diet.
Combustion in a furnace and combustion in the body are apparently very dissimilar; but, generally speaking, they are the same from a chemical standpoint. The former takes place rapidly, with the evolution of heat and usually of light; the latter more slowly and inconspicuously. If the food is likened to fuel and the body to a furnace, the respiratory products given off by the lungs correspond to the smoke and other combustion products which pass out through the flue. The solid and liquid excretory products of the body correspond in a way to the ashes of a furnace, which, of course, are made up of materials which could not burn completely and partly burned fragments that for some reason escaped combustion. One important difference between the human body and the furnace or steam engine is that the former is self-building, self-repairing, and self-regulating. Another is that the material of which the engine is built is very different from that which it uses for fuel; but in the case of the body part of the material which serves it for fuel also builds up and maintains the body tissue. Furthermore, if food is withheld the body can for some time use its own substance for fuel. This the engine can not do.

Obviously the body is more than a machine. It has not simply organs to build and keep in repair and supply with energy; it has a nervous organization, and it has sensibilities and higher intellectual faculties. It is, perhaps, not too much to say that the right exercise of all our faculties must ultimately depend upon the nourishment of the body which renders their existence possible.

In the case of an engine everyone recognizes the fact that one sort of coal may be more satisfactory and economical than another because it burns better and gives more heat per ton. It is equally true that one food may be more satisfactory than another because it is more thoroughly digested, more wholesome, or is a better source of energy. To determine the efficiency of an engine we need information regarding such factors as the energy or heat value of the fuel, the amount of ash and of waste products carried off through the flue, the quantity of fuel required for different kinds of work, the quantity of energy in the fuel which can be converted into useful work, and related questions. It is equally true that in the case of the body we need to know the most wholesome kinds of food, the relative amounts of waste material in different sorts, the amount and composition of the waste products and their relation to food and work performed, the amount of work possible on a given ration, and, in short, the best and most economical food for maintaining the body machine in perfect condition and enabling it to perform the necessary amount of physical and mental work.
Bearing these various facts in mind, the need of some satisfactory laboratory apparatus for studying problems connected with the income and outgo of the body, the use which it makes of its food supply, the work which it performs, the value of different food combinations, and similar questions will be readily recognized. To meet such needs an apparatus has been devised in connection with the nutrition investigations of the Department of Agriculture. Since it permits of the measurement of the gases of respiration as well as the heat liberated from the body, it is called a respiration calorimeter. In the planning and carrying out of this work, which was begun in 1892 by Wesleyan University and the Storrs Experiment Station, the Department of Agriculture has cooperated since 1894.

In its general design the respiration calorimeter was inspired by the Pettenkofer apparatus, built about fifty years ago at Munich. Pettenkofer directed his attention chiefly to the measurement and analysis of the respiratory products, but in planning the respiration calorimeter used in the Department of Agriculture experiments the income and outgo of energy was taken into account as well, these factors being most conveniently measured as heat. After a considerable amount of experimenting the Atwater-Rosa respiration calorimeter was completed and has been used for a large number of experiments with satisfactory results.

In this instrument a current of air was pumped through the respiration chamber, and by ascertaining its composition and volume it was possible to learn the amount and character of the respiratory products given off by the subject in the apparatus, though it was not possible to measure directly the amount of oxygen used. This was felt to be necessary and the apparatus was accordingly modified by the introduction of new features, including devices for the direct measurement of oxygen, the expenses for these improvements being defrayed by the Carnegie Institution of Washington. This new form of respiration calorimeter is here briefly described.

DESCRIPTION OF THE RESPIRATION CALORIMETER.

GENERAL PLAN.

The apparatus consists of an air-tight copper box, surrounded by zinc and wooden walls with air spaces between, and is large enough for a man to remain in it in comfort for a number of days. A ventilating current of air is pumped through the chamber or box at such a rate that the subject can always be supplied with a sufficiency of pure air. The chamber contains a folding bed, chair, table, etc., and is provided with means for the introduction of food and drink and the removal of excreta. The ventilating current of air as it leaves the apparatus passes...
through purifying vessels that remove the carbon dioxide and water vapor which make up the respiratory products given off by the lungs and skin. Fresh oxygen is then added to the air current to make up for that withdrawn by the subject for the internal process of combustion in the body. When purified and laden with oxygen so that it is fit to be breathed the air current is again passed through the respiration chamber, this circulation of air being kept up as long as the

Fig 10.—General plan of respiration calorimeter laboratory.
FIG. 1.—Respiration Calorimeter, General View.

FIG. 2.—Respiration Calorimeter, Side View.
The arrangement of the whole apparatus with its accessories is shown in figure 10. This gives a plan of the calorimeter laboratory, which is located in one of the rooms of the chemical department of Wesleyan University at Middletown, Conn.

On the north side is the respiration apparatus. Just south of this is the absorption system, through which the ventilating air current passes as it leaves the chamber charged with the respiratory products given off by the subject. The direction of the current is indicated by arrows. The air current as it leaves the chamber is first drawn through sulphuric acid, which absorbs the moisture in the air, and then through soda lime, which absorbs the carbon dioxide—that is, these two systems of absorbers free it from the products of respiration. After the oxygen is added the air passes back to the chamber pure and wholesome and ready to be breathed again. The circulation of the current is maintained by air pumps operated by electric power. On the east side is the observer's table, at which the assistant sits who attends to regulating the temperature within the apparatus and records the observations which are made during the progress of an experiment.

A general view of the apparatus taken almost opposite the observer's table is given in Plate IX, figure 1. A side view, showing the purifying arrangements through which the ventilating current of air is passed, is shown in Plate IX, figure 2.

HEAT REGULATION AND MEASUREMENT.

A study of the heat given off by the human body on different diets, different conditions of work and rest, during sleeping and waking, and so on, is a very important matter in considering the functions and uses of food and the efficiency of the body as a machine. The energy value of food, coal, or other material can be readily learned by burning samples and measuring the amount of heat given off. The way in which the body uses the energy supplied by the food can be very conveniently studied with the respiration calorimeter. One of the most interesting features of this apparatus is found in the devices for measuring the heat given off from the body and regulating the temperature of the chamber so that the subject may be always comfortable.

Houses are very commonly warmed by a current of hot water which passes through radiators and gives off its heat into the rooms. If a current of cold liquid were circulated through the pipes it would absorb the heat and the room would be cooled, as is obvious when we remember that a similar plan is followed in cooling cold-storage chambers. In the respiration chamber a current of cold water passes through pipes which have a large surface, so that they may the more readily absorb the heat. As the water enters and again as it leaves, its temperature is noted. The amount of water passing through the pipes in a given time is also ascertained. Knowing the weight of water, the
rise in temperature, and the specific heat of the water, the amount of heat absorbed and carried out of the chamber by the water current may be readily calculated. The colder the water on entering the more readily will it absorb heat in its passage through the pipes, and, conversely, the warmer the water on entering the more slowly will it carry away the heat. Therefore, when the subject is working hard and giving off heat from his body rapidly the water current is cooled nearly to zero by passing it through cooling tanks before it enters the chamber; at the same time the rate of flow is increased. On the other hand, when the subject is at rest, especially during the hours of sleep, when muscular activity is reduced to a minimum, and the heat production of the body is at a low ebb, the water current is allowed to enter at a higher temperature and a slower rate. During the period of deep sleep the subject ordinarily gives off heat from the body at the rate of 60 to 75 calories per hour, or enough to raise the temperature of 1.3 to 1.7 pounds of water from freezing to boiling. When he rises and sits quietly the hourly rate increases to 100 or 115 calories. When he works on a stationary bicycle, which is part of the equipment of the respiration chamber and used in work experiments, it reaches 300, 450, or even 600 calories per hour. Special devices are provided for taking account of these sudden changes in the rate of heat production.

The rapidity with which the heat given off by the subject is absorbed by the water current and brought out of the chamber is controlled by the observer, who sits at the observer's table outside of the apparatus. In practice the heat is brought away from the chamber just as rapidly as it is given off by the body, and consequently the temperature of the chamber is kept very constant. Delicate electrical thermometers indicate the temperature to one one-hundredth of a degree, and any slight temporary rise in the temperature of the chamber like that which would result from an increase in heat production because of movement of the subject, such as rising from his chair, stretching out the arms, or moving in bed, can be at once detected by the observer.

MEASUREMENT OF RESPIRATORY GASES.

In a study of the relative value of different foods for the body it is very important to know the amount and composition of the excretory products, including those given off through the lungs, in order that we may strike a balance between the income and outgo of the body and learn how much of the food material is retained and utilized. The visible excretory products may be readily weighed or measured and analyzed. In the case of the equally important invisible products the necessary measurements may be made with the aid of the respiration

---

*A calorie, as the heat-measuring unit is called, is an amount of heat which would raise the temperature of 1 pound of water 4° F.*
calorimeter. The determinations include, among others, the collecting and weighing of all the water vapor and carbon dioxide given off by the body and the exact measurement of the oxygen used by it, oxygen being, it is hardly necessary to say, one of the principal constituents of the air and that portion of it which is essential for the oxidation of food materials in the body.

The ventilating air current pumped through the chamber brings out the water vapor and carbon dioxide. The outgoing air necessarily contains less oxygen than the incoming air, since some has been withdrawn for the uses of the body. The air current first passes through a vessel containing concentrated sulphuric acid or oil of vitriol, which completely deprives it of moisture. The dry air, containing the carbon dioxide and still deficient in oxygen, is then passed through a mixture of caustic soda and quicklime (so-called soda lime), which rapidly absorbs all the carbon dioxide. The arrangement of the water and carbon dioxide absorbers is shown diagrammatically in figure 10, and in their actual position in Plate IX, figure 2.

At the left side of the frame in which they stand are two sulphuric-acid cylinders, which take up the water; then follow three soda-lime cylinders for the absorption of carbon dioxide, and then another sulphuric-acid cylinder to retain any moisture which the air current may have taken up from the soda lime, which always contains a little water. Freed from both carbon dioxide and water, the air then passes on to the air pump at the right and is returned through the pipe along the top of the shelf, which may be seen in Plate IX, figure 2, above the absorbers. As it passes through this pipe measured amounts of oxygen are added to the air current from a cylinder of compressed oxygen, such as is used for many commercial purposes.

**TESTS OF THE ACCURACY OF THE RESPIRATION CALORIMETER.**

The purpose of the apparatus, as has been stated, is to measure accurately the oxygen used and the carbon dioxide, water, and heat given off by the subject during an experiment. It was necessary to subject the apparatus to rigid tests as to its adaptability for this purpose. The factors involved in the combustion or oxidation of food material in the body and the products evolved are the same as in the burning or oxidation of alcohol in a lamp, and the quantities of heat and combustion products, corresponding to a given weight of alcohol, are accurately known. It follows, therefore, that if known quantities of alcohol are so burned in the respiration chamber as to insure complete combustion, a comparison of the measured amounts of oxygen, water, carbon dioxide, and heat with the theoretical amounts will serve as a critical test of the accuracy of the apparatus and method.
Many such tests have been made with the respiration calorimeter, and on the whole the results obtained are very satisfactory, indicating that the measurements made with it are very accurate, and that the apparatus is suited for the physiological experiments referred to.

**KIND OF EXPERIMENTS WHICH HAVE BEEN MADE.**

The purpose of the experiments with the respiration calorimeter is to study the fundamental laws of normal nutrition, and so far all the experiments have been made with active men in good health—that is, with normal subjects. The majority of them have been laboratory assistants or students of mature years. The experiments have covered varying conditions of diet, work, rest, etc. The food which has been selected for the experimental diet has been carefully chosen, so that it might be suited in quantity and composition to the subject's needs and the purpose of the experiment, and the diet has been made palatable in order to insure normal results. In some of the experiments the subject, for purposes of comparison, has had a limited food supply or has fasted.

In the rest experiments a minimum amount of muscular exercise has been performed, the subject reading or writing a little to pass the time agreeably. In other experiments he has engaged in more or less active muscular or mental work. In connection with many studies of the body changes during muscular work a bicycle ergometer (shown in fig. 11) has been used, which permits of very accurate measurements of the external muscular work applied to the pedals. This instrument is placed inside the respiration chamber and is there ridden by the subject.

In appearance the ergometer resembles a bicycle with the front wheel removed, and the subject sits upon it and operates the pedals exactly as on a bicycle. In place of the rear wheel, however, there is a copper disk of about the same diameter as the wheel, the frame of the apparatus being raised enough to keep the disk from the floor. This disk revolves between the two poles of an electro-magnet. When there is no current passing through the magnet the disk may be turned very easily, and though turning it involves some muscular movement the quantity of work actually done is small. When an electric current is passed through the magnet it acts as a brake, and more effort is required to turn the disk, consequently more work is involved. The advantage of such a brake is that the amount of resistance actually applied can be measured. By varying the current passed through the magnet and the speed with which the disk is revolved, it is possible to control the amount of work performed, which may be measured. Experiments have shown that the apparatus gives very accurate results.

Some of the experiments with the respiration calorimeter have occupied only a few hours, but the majority have lasted from two to four
days and nights. Frequently several experiments follow one another, so that the subject passes ten or more consecutive days without leaving the respiration chamber.

The labor involved in conducting a complete experiment can be judged approximately when it is stated that the entire time of sixteen men is required to carry on an experiment properly. The food for the subject must be prepared and each portion weighed, the liquid and solid excreta must be measured or weighed, and suitable samples of both food and excreta prepared for analysis. The ventilating air current must be regulated, the oxygen supply controlled, and the amounts of carbon dioxide and water withdrawn by the absorbers determined by weighing from time to time. The temperature of the air inside the chamber must be kept constant, which necessitates hundreds of readings of the thermometers. The water current which removes the heat from the chamber must be controlled, and the amount of water passing through in a given time and its temperature on entering and leaving the chamber recorded at short intervals. The power which drives the air pumps and other machinery must be watched, and the whole complicated apparatus must be kept in perfect working order. All this necessitates thousands of weighings and measurements and the recording of a large mass of experimental data, as may be readily seen when it is remembered that some of the records are taken at intervals of two or three minutes, night and day.
After the experiment is completed numerous detailed analyses of food and excretery products must be made and the results of the experiment calculated, compiled, and tabulated. The experiment continues night and day, the day force being relieved by a corps of night assistants. The subject sleeps quietly within the chamber, and so regular is his life that a definite programme, which is drawn up in advance, is followed day by day.

At the time of writing 72 experiments with 9 different subjects, covering a period of 209 days, have been completed. In these experiments the total income and outgo of both matter and energy have been measured and studied. These experiments and the deductions from them are reported in detail from time to time in bulletins of the Office of Experiment Stations. Some of the more important results may be spoken of here.

**SOME RESULTS OF THE EXPERIMENTS.**

**AMOUNTS OF CARBON DIOXID AND HEAT GIVEN OFF BY THE BODY.**

When coal is burned in a stove heat is generated and a gas known as carbon dioxid is given off, together with water vapor. In exactly the same way, but less rapidly, when food is burned in the body heat is generated and water vapor and carbon dioxid produced, the heat being constantly radiated from the body and the water vapor and carbon dioxid given off by the lungs and skin. The amount of heat given off by the body depends to a very large extent upon the amount of muscular activity, while the amount of water vapor and carbon dioxid eliminated depends upon both muscular activity and the kind of material which is burned in the body, whether it be protein, as the lean of meat; fat, like butter fat; or carbohydrates, such as starch or sugar; or a combination of these.

In the experiments which have been made with the respiration calorimeter all grades of muscular activity have been tested from deep sleep with a fasting subject to the excessive muscular work of a professional bicycle rider. When muscular work was performed other than that involved in the body motions essential to eating, drinking, and moving about in the respiration chamber, the muscular exercise consisted in operating the bicycle-like apparatus shown in figure 11. Light muscular exercise consists in running the wheel with no resistance. For moderately active muscular work a fair amount of resistance is applied by means of the electrical brake, and the rider turns the wheel at a definite number of revolutions per minute for a stated period. In severe work the resistance is kept the same and the number of revolutions increased or the resistance is increased and the

---

*Department of Agriculture, Office of Experiment Stations Bulletins Nos. 44, 63, 69, 109, 186.*
revolutions kept the same. For very severe work either the resistance or the number of revolutions, or both, are still further increased. The results of the experiments, showing the output per hour of carbon dioxide and heat from the body under the different conditions indicated, are here summarized.

**Average normal output of carbon dioxide and heat from the body.**

<table>
<thead>
<tr>
<th>Conditions of muscular activity</th>
<th>Average quantities per hour.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbon dioxide.</td>
</tr>
<tr>
<td>Man at rest, sleeping</td>
<td>25</td>
</tr>
<tr>
<td>Man at rest, awake, sitting up</td>
<td>35</td>
</tr>
<tr>
<td>Man at light muscular exercise</td>
<td>55</td>
</tr>
<tr>
<td>Man at moderately active muscular exercise</td>
<td>100</td>
</tr>
<tr>
<td>Man at severe muscular exercise</td>
<td>150</td>
</tr>
<tr>
<td>Man at very severe muscular exercise</td>
<td>210</td>
</tr>
</tbody>
</table>

From the above table it may be seen that the output not only of heat but of carbon dioxide is very nearly proportional to the amount of muscular work. The average results quoted furnish data for estimating the amount of carbon dioxide and heat given off daily by men with varying degrees of muscular activity. For example, if a man sleeps 8 hours per day, we may say that the carbon dioxide output during this period is approximately eight times the hourly amount eliminated during sleep by the average subject, or 8 by 25 = 200. If he is at very severe muscular labor for 8 hours the carbon dioxide output would correspond to eight times the hourly amount for very severe work, that is, 8 by 210 = 1,680, and if the remaining 8 hours of the day were devoted to going to and from work, eating, sitting, etc., corresponding, say, to 6 hours of rest and two hours at light muscular exercise, the carbon dioxide output will be six times the average amount eliminated per hour at rest, that is, 6 by 35 = 210 grams, and two times the amount given off at light work, 2 by 55 = 110 grams. The total for the 24 hours would obviously be the sum of the quantities mentioned above, or 2,200 grams. The heat eliminated in the 24 hours by men at very severe work may be likewise calculated by multiplying the time devoted to sleep, work, etc., by the average hourly output. In 8 hours at sleep he would eliminate 520 calories (8 by 65 = 520); in 8 hours at work, 4,800 calories (8 by 600 = 4,800); in 6 hours of rest, 600 calories (6 by 100 = 600), and in 2 hours at light exercise, 340 calories (2 by 170 = 340), making a total for the 24 hours of 6,260 calories.

For individuals at different occupations the chief variations in a calculation like the above would be concerned with the 8 hours devoted to work, as the conditions for the remainder of the 24 hours, that is, the time devoted to sleep, rest, and the light exercise involved in
going to and from work, etc., would be much the same in the majority of cases. Knowing the kind of work performed and the number of hours devoted to work and sleep, it will be seen that the calculation with reasonable accuracy of the total energy and carbon dioxid given off by the body is a very simple matter.

Thus, we see that, as a result of a large number of measurements made in the respiration calorimeter on a number of men, it is possible to obtain an important series of factors which, it may be stated, were not available until these experiments were carried out. These factors are of great value in estimating the needs of the body for food under varying conditions of exercise and muscular work, since, as has been previously stated, the energy output of the body is dependent upon the energy supplied in food.

VENTILATION.

In experiments with the respiration calorimeter the air which the subject breathes is analyzed with the greatest care, and it is obvious that since his physical condition is studied in relation to the character and amount of the air supplied the experiments may be made to furnish much data regarding problems of ventilation. In some of the experiments the rate of ventilation was much lower than has hitherto been considered possible.

Normal air contains about 3 parts of carbon dioxid per 10,000, and writers on ventilation have emphasized the importance of having the air in rooms changed so frequently that the amount of carbon dioxid will not become much greater than this. It was found that, in order to keep the air in the respiration chamber at so low a carbon-dioxid content, the rate of passage of the ventilating current must be so great that the pumps and analytical apparatus would be strained to their utmost capacity. In a long series of experiments it was found that the subject could get along apparently as well with a much lower rate of ventilation, that is, with much more carbon dioxid in the air, so that at present the ventilation is less than one-tenth of that usually advocated, and the carbon dioxid content is never less than 8 to 10 times the normal amount, and frequently for short periods it is as high as 50, 60, or even 80 times the normal proportion. It should be borne in mind, however, that the air is kept dry and otherwise pure, since the passage through the sulphuric acid of the absorber system would remove water and any unpleasant products which might be excreted, as in the breath.

The extent to which this high vitiation of air has been carried with no appreciable effect may be seen from an experiment made in the winter of 1904. If the atmosphere breathed by the subject contains abnormally high amounts of carbon dioxid, it is easy to conceive that the normal respiration might be interfered with. To test this
point the subject was made to wear over his face for 24 hours a light mask, connected with air pipes through which he was compelled to breathe. These pipes passed out through the chamber and carried away the products of respiration, so that the air in the chamber did not become vitiated. Under these conditions the subject breathed normal air for 24 hours, the amount of carbon dioxide produced and oxygen consumed being accurately recorded. During the next 24 hours the mask was removed and the subject breathed the air in the respiration chamber. The rate of ventilation was very much reduced and the amount of carbon dioxide in the atmosphere allowed to accumulate to such a degree that the subject was living in an atmosphere containing 226 parts of carbon dioxide per 10,000, or 2.3 per cent. This degree of vitiation is perhaps greater than men have ever lived in save in exceptional conditions when they have lost consciousness in closed chambers, as in caissons, submarine boats, etc. It would have been impossible to light a match or burn a candle in the respiration chamber during the experiment, yet the subject, who was purposely not told anything regarding the degree of vitiation, was indifferent to the atmospheric conditions. He read, slept, communicated with the observers through the telephone, ate his meals with the usual regularity, and, indeed, was so pleased to be relieved from the necessity of wearing the mask, as on the day before; that he was in excellent spirits.

It would be natural to suppose that with so great vitiation of the air the subject would feel languid, mentally inefficient, and would possibly lack appetite, yet none of these effects was noticeable. It appears that on the day in which the subject wore the mask and breathed pure air, and on that in which he breathed the air with a high carbon-dioxide content but without knowing that this was the case, the amounts of heat evolved, carbon dioxide produced, and oxygen consumed were practically the same. In other words, as shown by experimental measurements and his physical and mental condition, it was immaterial to this subject whether he lived in an atmosphere containing a normal amount of carbon dioxide or whether he was breathing air containing almost eighty times the normal quantity.

It should not for a moment be inferred, however, that such an experiment is a logical argument for poorer rather than better ventilation, for of the several factors concerned in insufficient ventilation only one, the carbon-dioxide content, was here studied. Ventilation problems must also take into account the diminished oxygen content, excessive moisture, excessive heat, and related conditions.

It must be borne in mind that during the experiments recorded the water content of the air and the temperature of the chamber were both regulated with great accuracy and were approximately normal. That we need as large an amount as possible of pure fresh air of even
temperature is no longer questioned by anyone, but that the amount of carbon dioxide is in itself as important a factor in the vitiation of air as has been commonly supposed can hardly be believed in view of these experiments. The whole subject is one which should receive further attention, and it seems only fair to say that the respiration calorimeter offers a method of experimenting which promises more in the way of useful results than those which have been hitherto followed.

BODY TEMPERATURE.

One of the interesting problems which have been studied in connection with the respiration calorimeter experiments is that of body temperature, its normal fluctuations, the extent to which it is influenced by external conditions, and related questions. Our bodies are continually generating heat by the internal oxidation of food and simultaneously giving off heat by radiation, etc. Obviously, if the heat elimination is so regulated that the amount lost in a given time is the same as that generated there will be no change in body temperature, and that such a regulation exists is shown in the fact that as long as the body remains in health it has a temperature not far from 98° F.; indeed, this temperature is commonly marked on thermometers as blood heat. If, however, there is a disturbance in the body mechanism a rise in temperature is commonly noted. When this is at all marked we designate it fever. Doubtless few persons realize that normally the body temperature undergoes a daily variation of not far from 2° F. Between 2 and 4 a. m. the body temperature is at its lowest point, and generally about 4 to 6 p. m. it is at its highest point. With the ordinary clinical or fever thermometer of the physician one would not be apt to recognize clearly this variation in normal body temperature, but with the delicate electrical thermometers used in connection with the respiration calorimeter experiments it is possible to demonstrate it and, indeed, to study very minute variations in body temperature with great accuracy.

A physician usually takes the temperature of a patient by having the thermometer held in the mouth under the tongue until it has assumed body temperature. In the experiments referred to it has been found much more advantageous to take it in the intestine, inserting the thermometer in the rectum. The thermometer used is very flexible. It is constructed of copper wire coiled in a silver tube, the wires leading to the instrument where the temperature is measured being covered with soft rubber tubing. The thermometer can be worn day and night without discomfort. When worn by a subject inside the respiration chamber the changes in temperature are indicated by means of a galvanometer, and are recorded by the observer outside, together with the other experimental data. The subject is
undisturbed by the experiments which are being made, goes about his usual daily routine, and at night sleeps undisturbed, although his body temperature is being measured to the hundredth of a degree every four minutes. As the result of a large number of experiments, it has been found that the body temperature falls off rapidly on going to bed and continues to fall slowly until a minimum is reached early in the morning. There is a rapid rise in temperature between 6 and 8 a.m., followed by a slower rise during the day, the maximum being reached between 4 and 6 p.m. In the evening the temperature again falls gradually until the time of retiring, when, as stated above, it drops rapidly. This is, of course, the average temperature fluctuation. It is surprising to note that in the majority of cases studied individual variations from the normal are very slight.

Many of the results regarding body temperature which have thus far been obtained serve only to verify the work of earlier investigators. Nevertheless, as a whole, it is believed that they contribute a by no means unimportant chapter to our knowledge of temperature fluctuations, especially during sleep, a period which at best could be but poorly studied by the ordinary methods of thermometry.

A knowledge of normal variations in body temperature and the effect of various factors on it can not fail to be of use to physicians, especially in cases where treatment is based to a considerable degree on the indications given by temperature charts. The experimental methods indicated above furnish a convenient way of studying the whole question of body temperature, its cause and determining factors, its relation to external temperature, work and rest, and other factors. The subject is one which is closely related to that of the effect of hot and cold climates on the body and its food requirements and power to produce useful work. In the respiration chamber it is possible to maintain at will high or low temperature and humid or dry air, and by its aid many problems like those indicated can be studied.

All know that there are marked differences in our feelings of physical comfort dependent upon the materials of which our clothing is made, that is, the amount and kind of protection from heat or cold which it affords the body. This is in part due to the character of the articles worn, that is, whether they are linen, wool, cotton, or silk, and is in part due to the fineness of weaving, the closeness with which the clothing fits the body, and the general character of the textiles selected. Certain fabrics hinder the radiation of heat from the body, and so keep it warmer than others. In the same way we associate coolness with certain materials and colors. The completeness with which water vapor, that is, perspiration, is absorbed by clothing or allowed to pass away from the body surface is also a factor of great importance in judging of the relative merits of different fabrics. The relative value of various textiles for hindering radiation—keeping
the body warm—and of others for helping radiation—keeping the body cool—may be readily studied with the respiration calorimeter, as may numerous other problems connected with the hygiene and comfort of dress.

CONCLUSION.

In the preceding pages the respiration calorimeter has been briefly described, the methods of operating it have been discussed, and some of the results which have been obtained with it briefly spoken of. Many other important problems have been investigated, and a large amount of experimental data has accumulated. All the questions studied have to do with the fundamental laws of nutrition, and, in brief, it may be said that it is in seeking knowledge regarding these laws that the respiration calorimeter finds its greatest use. With this and the accessory apparatus, combined with the chemical and physical methods of analysis common to all well-equipped laboratories, the complete intake of food, drink, and air, expressed in terms of chemical elements and energy, and the complete output of energy and gases, solid and liquid excreta, and heat may be ascertained. By comparing one with the other we can determine whether the body has gained or lost material or produced more energy than it has received. Continuing experiments through comparatively long periods and under a very great variety of conditions, we are enabled to measure the effects of food and fasting, rest, sleep, muscular and mental activity, and other conditions upon the food requirements, the amount and character of the excretory products, the changes which the matter and energy supplied by the food undergo in the body, and the effect of external conditions and body changes upon the comfort and well-being of the subject.

When we remember that numerous problems relating to hygiene, ventilation, climate, and related questions can also be studied, it is obvious that the investigator has a wide field for his efforts.