ENERGY TRANSFORMATIONS DURING HORIZONTAL WALKING

BY

FRANCIS G. BENEDICT

AND

HANS MURSCHHAUSER

WASHINGTON, D. C.

PUBLISHED BY THE CARNEGIE INSTITUTION OF WASHINGTON

1915

CARNEGIE INSTITUTION OF WASHINGTON
PUBLICATION NO. 231

9406

PRESS OF GIBSON BROTHERS, INC.
WASHINGTON, D. C.

CONTENTS.

ILLUSTRATIONS.

ENERGY TRANSFORMATIONS DURING HORIZONTAL WALKING.

INTRODUCTION.

This investigation was undertaken after several long conferences with Professor Zuntz of Berlin and Professor Durig of Vienna, whose researches on the work of forward progression are classical. The preliminary experiments were made during the sojourn at the Nutrition Laboratory of Dr. Carl Tigerstedt of Helsingfors. Subsequently data were acquired by Messrs. H. L. Higgins and L. E. Emmes of the Laboratory staff. We wish to express our thanks to these gentlemen and particularly to Dr. Tigerstedt for the data regarding Subject I.

A certain amount of walking on a level inevitably forms a part of the daily routine of nearly every living person, for even those who are designated as sedentary in their habits do a not inconsiderable amount of walking in the house or in short distances upon the street. To one who has not computed the actual distance traversed by the housewife during a day, the sum total of the distance walked is surprising. Such a control may readily be obtained with a simple pedometer, for although a pedometer can not be classified as an instrument of precision and is subject to many errors that are frequently overlooked, nevertheless it shows in a striking manner that very few individuals close a day of ordinary life without having moved in forward progression a distance of not less than 2 or 3 kilometers.

Not infrequently this distance is doubled or trebled by those who would ordinarily assume that they had not taken a particularly long walk. The personal experience of one of us while writing a report showed that the walking for a day consisted in going twice to and from the house, which was 400 meters from the laboratory, *i. e.*, a total distance of 1,600 meters, and in walking about the laboratory while engaged in instruction and research. Throughout a period of several months the pedometer, which was carefully controlled and tested, showed that the average distance walked per day amounted to 7 miles (11.27 kilometers).[1] Undoubtedly innumerable instances even more striking than this may be cited, which would show that it is reasonable to assume that practically all persons do considerable walking during the course of 24 hours. Inasmuch as there are many individuals whose habit of life or profession requires a large amount of walking—for example, those walking to and from business, mail carriers, and espe-

[1]Benedict, Proc. Am. Phil. Soc., 1910, **49**, p. 162.

cially soldiers—an intimate knowledge of the physiology of walking is obviously of great importance.

Practically all of the previous researches on the physiology of walking have been conducted either from a desire to study the conditions incidental to walking done in mountain climbing, the results being of importance to physicians and those taking regular exercise, or, as in the case of the classical researches of Zuntz and Schumburg, from a desire to study the influence of walking on the metabolism, with a view to applying the results directly to army movements. In the present day, when special attention is directed towards efficiency, the minimizing of extraneous muscular movements, and the transportation of material by hand and leg motion with the least possible expenditure of physical energy, we may assume that there is every incentive for studying carefully the physiology incidental to walking in a horizontal direction.

While from the abstract physiological standpoint a study of all of the various factors incidental to walking is of great value, perhaps the most important phase of the investigation is the study of the energy transformations and the determination of the amount of nutrients in the food necessary to provide for such activity. The results of such study are of especial practical value in determining the energy requirements of an army engaged in marching a certain distance over a level country. As previously stated, this thought dominated the study of Zuntz and Schumburg. A more universal application of the results may be made by the physician who, if he knows the energy involved in walking, is able to prescribe more intelligently a definite amount of exercise for the ambulatory patient. Furthermore, as physical exercise, particularly walking, is an important factor in weight reduction and in athletic training, exact information as to the energy required may be put to practical use in such connection.

Theoretically the movement of 1 kilogram 1 meter would call for no positive work other than that in overcoming the resistance of the air; nevertheless a considerable amount of work is required of the human body as a machine in accomplishing this feat of moving the mass in a horizontal direction. The apportionment of the total energy output of the body between that required for the maintenance of the vital functions and that required for walking is not, however, simple. When a person is walking, not only is energy required for the external muscular exercise, but a heat production is necessary for the entire maintenance of the body activities, including muscular tonus, the work of circulation, respiratory muscles, and the external work of balancing the body in an upright position, none of these activities contributing directly to the work required to move the body in a horizontal direction. With only a knowledge of the amount of food eaten, it is impossible to estimate the proportion of food required for the activity of walking and that for vital maintenance. A closer analysis is therefore essential.

METHODS OF DETERMINING THE ENERGY TRANSFORMATIONS DURING WALKING.

It is necessary, first of all, to study the energy transformations which are peculiarly incidental to walking. Thus, in the simplest case, if the person could walk directly in a vertical direction, a definite amount of external muscular work wôuld be performed which would be represented by the product of the weight of the body and the height walked. In walking in a horizontal direction, theoretically no external work is performed and there is no change in the potential energy of the body. We are thus unable to measure the energy output by the kilogrammeter, the unit most commonly used, or by any of the other ordinary work units. Consequently we have very little information regarding the energy output.

It is true that we must not disregard the extremely illuminating researches of earlier workers, who have attempted to establish a constant, although with wide variations, which would show approximately the amount of energy required to move 1 kilogram 1 meter in a horizontal direction. These researches will be referred to in a subsequent section. It is important for us to note, however, that aside from such methods of calculation as are based upon the constant established by the earlier physiologists, we have no means of calculating the energy output required in walking.

A possible method of measurement would be to determine the energy output directly by having the subject walk inside of a calorimeter. This has been attempted, although in an imperfect manner, by certain French investigators, including Hirn[1] and Chauveau,[2] who used the so-called "emission calorimeter" with a tread wheel. In these studies, however, a large proportion of the work was done in lifting the body, and hence the amount of forward progression, which is of special interest to us, is complicated by the very much greater work involved in the elevation of the body.

Finally, it is possible, owing to the valuable computations and methods of research established by Zuntz, to study the respiratory exchange, namely, the carbon-dioxide output and the oxygen intake, and thus compute indirectly the total calorific output. This last method has been adopted by all physiologists as the most suitable for the purpose. Practically all previous research has therefore been based upon the general principle of determining the total respiratory exchange both while the subject is walking and during rest when lying, sitting, or standing, and noting the increment in the carbon-dioxide output and oxygen intake due to walking.

From the heat of combustion and analysis of pure nutrients, such as carbohydrate and fat, it has been computed that for each liter of

---

[1]Hirn, Recherches sur l'équivalent mécanique de la chaleur, Paris, 1858.
[2]Chaveau, Compt. rend., 1899, **129**, p. 249.

oxygen required in the combustion, there are produced from 4.686 to 5.047 calories. When pure carbohydrate is burned, each liter of oxygen utilized in the combustion corresponds to 5.047 calories, but when pure fat is burned each liter of oxygen corresponds to 4.686 calories. Zuntz and his co-workers have prepared a table showing the calorific equivalent of the oxygen consumption when fat and carbohydrate are burned.[1] This has been most ingeniously elaborated by Williams, Riche, and Lusk.[2]

By studying the output of carbon dioxide and the intake of oxygen, not only is information secured regarding the total oxidation of material, but also some idea is gained of the character of the combustion by noting the relationship between the volume of carbon dioxide given off and the oxygen absorbed. With equal volumes of carbon dioxide and oxygen, this relationship or "respiratory quotient" is 1.0 and indicates that carbohydrate has been exclusively burned. When the respiratory quotient approximates 0.7 the indication is that fat has exclusively been burned. By this means, therefore, it is possible to compute with great accuracy the heat output from the total oxygen consumption and the respiratory quotient.

In certain earlier researches, and especially prior to the time when methods were devised by which oxygen absorption could be more easily determined than formerly, the measurements of the carbon-dioxide output alone were used, but a much greater error is introduced into the computations by this method. Unfortunately, of the two factors, carbon dioxide and oxygen, that which is of the greater significance, namely, oxygen, is the more difficult of determination, while the measurement of the carbon-dioxide excretion is relatively a simple matter.

METHODS OF STUDYING THE GASEOUS EXCHANGE DURING WALKING.

Inasmuch as a study of the problem of the energy transformations during walking demands a careful study of the gaseous exchange, we find all the methods used based upon this principle. The simplest is that in which the subject walks inside a closed chamber by means of which the product of respiration—carbon dioxide—is easily collected. This method was first employed by Sondén and Tigerstedt[3] in the classical research with their large respiration chamber in the Karolinska Institute in Stockholm. This chamber had a capacity of 100 cubic meters and, unlike any respiration chamber previously used, permitted the subject free movement. When the subject walked back and forth across the room, a considerable distance could be traversed. At that time only the carbon-dioxide output was determined with this method.

[1]Zuntz and Schumburg, Physiologie des Marsches, Berlin, 1901, p. 361.
[2]Williams, Riche, and Lusk, Journ. Biol. Chem., 1912, **12**, p. 357.
[3]Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, **6**, p. 165.

A second method involves the attachment of certain breathing appliances, either nosepieces or mouthpiece, with an apparatus for measuring the volume of the expired air. When the breathing appliances have been adjusted, the subject assumes a certain body position and then walks along a movable path, such as a treadmill. This method was frequently used by Zuntz and Durig and their co-workers.

A modification of this method is that in which the apparatus for measuring and sampling the expired air is carried upon the back of the subject, somewhat as a knapsack would be carried. The subject is then no longer confined to walking upon a treadmill, but may walk on level ground anywhere. This method was used extensively by Zuntz and Durig and their associates and by Douglas. Instead of having the apparatus carried by the subject, it may be transported by an assistant walking a suitable distance behind him. The subject thus breathes through the nose or mouth appliance, but is not obliged to support the heavy apparatus. This method was employed by Burgi, Schnyder, and, in certain experiments, by Kolmer and Brezina.

Finally, it is possible to have the gas measuring and sampling apparatus in a fixed position and the subject attached to it by a long tube. He then walks in a clearly defined path, either back and forth across the room or in a circle of which the apparatus is the center. This method, which obviously limits appreciably the distance to be covered and the general freedom of the subject, has found slight use with certain French observers, particularly Amar.

FUNDAMENTAL PRINCIPLE OF STUDYING THE GASEOUS EXCHANGE INCIDENTAL TO WALKING.

The method of superimposition is the only one feasible for these studies. By this method the gaseous exchange during walking in different positions must be carefully studied by one or more of the methods previously referred to; subsequently, in order to apportion specifically the energy transformation due to walking, it is necessary that a certain part due to the metabolism of maintenance be subtracted from the result obtained for the total gaseous exchange.

The exact selection of the amount of energy transformed for maintenance to be deducted from the total energy transformation has been a matter of considerable discussion. We have now come to realize that a human individual may subsist on numerous metabolic levels. The subject sound asleep, without food in the stomach, has a minimum metabolism, but is utterly incapable of intellectual or physical activity. It would obviously be impracticable, if not indeed undesirable, to deduct this minimum metabolism from the measurement of the total metabolism and assume that the difference would be wholly due to the energy transformation due to walking. Even when the subject is lying awake, we still have a base-line which is far removed from the process of walking. To obtain the best expression of the superimposed energy requirement for forward progression, it is necessary to secure, as nearly as possible, the energy requirement of the subject in a position which involves all of the extraneous muscular movements incidental to the waking condition and in a vertical position. This may be obtained by deducting the metabolism required for the standing position. And yet the earlier researches have been most unsatisfactory in the attempts to measure the metabolism under these conditions.

With the standing position we again have numerous possible variations. The subject may stand in a completely relaxed position; he may possibly eliminate in a large part the effort of balancing by leaning on a staff or lying back slightly out of the vertical against a support; or he may stand in a fixed position with rigid muscles, such as that of "attention." We should, theoretically at least, expect to find a considerable difference in the metabolism necessary for these various upright positions.

Durig has clearly pointed out[1] that there are numerous arguments against assuming that the metabolism while standing in any one of these positions can rightly be deducted from that during walking to obtain the true energy transformation due to the walking, for it is quite possible that certain of the external muscular movements incidental to balancing and sustaining the body in an upright position may be greatly modified, if not indeed dispensed with, in the ordinary motions of forward progression. Consequently, one finds that, in previous researches, the base-line used almost universally among physiologists has been the metabolism observed with the subject lying awake without food in the stomach, *i. e.*, in the post-absorptive condition. The assumption is then made that the increment of metabolism during walking over that observed with the subject lying awake is a true measure of the metabolism due to the muscular exercise of moving the body in a horizontal direction.

UNITS OF MEASUREMENT USED IN WALKING EXPERIMENTS.

While under ordinary conditions the amount of work performed in any inanimate or animate motions is expressed in terms of foot-pounds, kilogrammeters, or calories, it is obvious that no one of these units can be appropriately employed for indicating the energy transformations during walking. In walking, a given weight is carried through a given distance. To be sure, there is inevitably a slight lifting of the total weight of the body at each step due to the anatomical arrangement of the feet and leg-muscles, but this weight is again immediately lowered to the same position, so that, mechanically at least, there is no effective work accomplished. The only external evidence of performance is that a given weight is moved forward a given distance.

In this discussion we may for the present appropriately eliminate the possible effect of wind resistance produced by the body in walking or the

[1]Durig, Denkschriften d. math.-natur. Klasse d. kaiserl. Akad. d. Wissensch., 1909, **86**, p. 267.

external influence of the wind in a direction either favorable or unfavorable for forward progression. But in practically all walking done by man considerable differences exist in the weight moved forward. With the bather walking on a flat sandy beach we have simply the weight of the body plus the negligible weight of the bathing-suit. On the other hand, with a pedestrian taking his "constitutional," we have the weight of the clothing, amounting to 3 or 4 kilograms, possibly supplemented by the weight of knapsack, camera, and other accessories. Finally we have the exaggerated case of the fully equipped trooper carrying knapsack, emergency rations, and a considerable quantity of ammunition. Thus we have the possible necessity of distinguishing between the movement due to the lifting of body-weight and that due to lifting inert or dead weight.

The subject is further complicated when we attempt to analyze the weight of the living organism. The body is made up of bone, muscle, and fat. Fat may be looked upon as inert body-material, and when there is an excessive accumulation of fat, as with obese persons, it is possible that it may be considered in great part as dead weight. It is thus seen that the problem of studying the physiology of forward progression involves the question of analyzing the character of the weight transported. For the present the unit of accomplishment in the work of forward progression on a horizontal plane must be considered as the transportation of 1 kilogram 1 meter, *i. e.*, 1 "horizontal kilogrammeter."

PREVIOUS RESEARCHES ON THE GASEOUS EXCHANGE DURING WALKING.

Before reporting and discussing the results of our own experiments, a brief abstract is given of all previous research in which the metabolism during walking has been studied. In thus reviewing the work of other investigators, it has seemed advisable to record the results on the basis of the movement of 1 kilogram over 1 meter of level path, *i. e.*, 1 horizontal kilogrammeter, and to compare them in a large summary table rather than to give them under each research. This is done in table 1 (see pages 22 to 27).

Observations of Smith, 1859.—The earliest attempt to measure the gaseous metabolism during walking was made by Edward Smith, who, in his memoirs entitled "Experimental inquiries into the chemical and other phenomena of respiration and their modifications by various physical agencies,"[1] gives the details of two walking experiments. In these experiments Smith collected the products of respiration by attaching a mask to the face and forcing the expired air through specially constructed boxes, containing caustic potash to absorb the carbon dioxide. The mask had two openings, one for inspired air and the other for expired air, a valve system providing for the separation of the two currents of air. A dry gas-meter was attached at the intake point. The expired air was first passed through a Woulff bottle containing pumice-stone and sulphuric acid, then into a gutta-percha box containing a solution of caustic potash, and finally through a second Woulff bottle containing pumice-stone and sulphuric acid. The walking was done inside of a room and covered a distance of approximately 10 meters in each direction. All of the precautions incidental to modern experiments as to recording the barometric temperature and pressure were taken, and a further factor, which is only too frequently neglected in modern work, namely, pulse-rate, was also recorded. The subject carried a spirometer which weighed 7 pounds, but the exact method of transportation is not clear from Smith's description. Both experiments were made in one afternoon, with an intermission of an hour. During the first experiment he walked at the rate of 2 miles an hour and during the second at the rate of 3 miles an hour. For a base-line he determined the metabolism at rest without food and in a sitting position.

Smith's values, which are given in English grains, were recomputed to grams by Sondén and Tigerstedt.[2] While walking at the rate of 2 miles an hour, the carbon dioxide per minute was 1.173 grams; at 3 miles an hour, 1.674 grams; and sitting at rest without food, 0.482 gram. The energy per horizontal kilogrammeter computed from these values is given in table 1, page 22. The results obtained by Smith have been criticized by Gruber[3] and Voit,[4] who both consider them

[1]Smith, Phil. Trans. Roy. Soc., London, 1859, **149**, p. 681.
[2]Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, **6**, p. 166.
[3]Gruber, Zeitschr. f. Biol., 1891, **28**, p. 470.
[4]Voit, Hermann's Handbuch der Physiologie, 1881, **6**, p. 201.

somewhat high. Katzenstein[1] likewise considers the values too high and inexact and regrets that Smith did not state whether the walking was done on a level or on an incline. Although Smith gives the weight of the subject and the apparatus in one instance, Katzenstein criticizes the absence of body-weights for each experiment. Katzenstein's further criticism, that the carrying of the apparatus by the subject was a fault in the technique, is of special interest in view of the subsequent use of a portable gas-meter by Zuntz and his co-workers.

Observations of Gruber, 1891.—The unusual interest in mountaineering, which is particularly active in Switzerland, has resulted in a large number of physiological observations upon the effect of high altitudes on the human body. One of the earliest of the observations, which included measurements of the gaseous metabolism, was that of Gruber,[2] who published the results of a research carried out in the Physiological Institute at Berne under the direction of Professor Kronecker. Gruber himself was the subject of the study.

Instead of using a mask with two valves, Gruber employed a tube in the mouth for expiration, the nose being closed by the fingers of the left hand. During inspiration the rubber tube leading to the mouth was tightly closed by the teeth and air was inspired through the nose. The inspired air was passed into a U-tube containing soda to absorb the carbon dioxide. A rubber air-cushion, which could be compressed by the arm of the subject, permitted the accumulation of the excess of air during the expiration, and during inspiration this air was forced out through the absorbing vessels by pressure with the arm.

Three experiments are reported in which the subject walked without other load than the apparatus. The rate of walking in the first experiment was 80 steps per minute. Two of the three experiments consisted of 10 minutes of walking followed by 10 minutes of sitting, Gruber concluding from his results that apparently as much carbon dioxide is excreted in the 10-minute rest after the short walking-period as during the walking. He also made three experiments while sitting in a chair prior to walking and two experiments after walking. On the basis of the sitting values he contends that with walking on a level the carbon-dioxide production is twice as great as with sitting. Both the rest and walking experiments were made 5 or 6 hours after food. Comparing the results of observations made both in trained and untrained condition and considering the amount of carbon dioxide produced during rest as 1, he obtained the following figures:[3]

	Rest.	Walking.	Ascent (untrained).	Ascent (trained).
Series 1...	1	[1]2.00	4.1	3.3
Series 2...	1	1.75	3.05	2.42

[1]Incorrectly stated as 1.89 by Gruber and recalculated by us.

[1]Katzenstein, Archiv f. d. ges. Physiol., 1891, **49**, p. 331.
[2]Gruber, Zeitschr. f. Biol., 1891, **28**, p. 466. [3]*Ibid.*, p. 490.

From these data he concludes that the carbon-dioxide production of a working man is not a function of his work, since the metabolism decreases with practice.

Observations of Katzenstein, 1891.—In the walking experiments of Smith and Gruber, only the carbon-dioxide production was determined, and the first investigations, in which the oxygen consumption was also measured, were those carried out by Katzenstein[1] in Zuntz's laboratory in Berlin. Employing the Zuntz mouthpiece and valves for separating the inspired air from the expired air, Katzenstein sampled and analyzed the expired air, the measurement of the total amount of air expired being made with a gas-meter. There is considerable doubt as to the conditions of the experiments. In certain instances it is specifically stated that the subjects were in the post-absorptive state, *i. e.*, without food for 12 hours, but the general impression is given that in the majority of instances the experiments were not made with the subject in the post-absorptive condition. The rate of walking was from 51 to 92 meters per minute. The criticism was subsequently raised by Durig[2] that the treadmill was not completely level, there being a slight elevation of somewhat less than 1 degree. To provide a base-line for these observations, the metabolism of the subject was measured while he stood quietly upon the treadmill. Observations were likewise obtained with the subject in a lying position. The author concludes that the oxygen consumption for the unit of effective work is greater for small amounts of work than for large amounts, and that the respiratory quotient during work remains essentially unaltered. The computation of the values per horizontal kilogrammeter is given in table 1, page 22.

Observations of Sondén and Tigerstedt, 1895.—The large respiration chamber in Stockholm afforded sufficient space for experiments in which the work of walking could be measured.[3] The carbon dioxide alone was determined and with most of the experiments moderate amounts of food were taken. The body-weight with clothing was recorded before and after the experiment. The subjects walked from 3,000 to 5,920 steps per hour without a load. As a base-line the authors used a value found for three resting periods when the subject was sitting, these periods being between periods of walking; large differences are shown in the carbon-dioxide output per hour during the resting periods. The energy per horizontal kilogrammeter, as computed from the carbon-dioxide output during the walking experiments, is given in table 1, page 22.

Observations of Schumburg and Zuntz, 1896.—In connection with a series of experiments made in the Alps, Schumburg and Zuntz carried

---

[1]Katzenstein, Archiv f. d. ges. Physiol., 1891, **49**, p. 330.
[2]Durig, Denkschrift. d. math.-natur. Klasse d. kaiserl. Akad. d. Wissensch., 1909, **86**, p. 250.
[3]Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, **6**, p. 1.

out a number of observations in Zuntz's laboratory in Berlin, using the treadmill.[1] A dry gas-meter weighing 7 kilograms was employed and was carried by the subject. In most of the experiments the inspired and expired air were separated by a valve system and a mouthpiece and nose-clamp were used. It is interesting to note that in the severe work of going uphill in this series of experiments, the authors record that the breathing appliances were very uncomfortable, particularly the nose-clip. They accordingly trained themselves to inspire through the nose and expire through the mouth, a procedure which they satisfied themselves gave accurate results. To establish a base-line, numerous experiments were made with the subject in a sitting position, these being carried out in the laboratory in Berlin, in the hotel at Zermatt, and also in the camp and on the glacier in the mountains. Three walking experiments were made with Zuntz as subject in a room of the laboratory building and two on the treadmill, which was in a practically horizontal position. Two treadmill experiments were also made with Schumburg as a subject. The energy per horizontal kilogrammeter, as computed from the difference between the sitting values and the walking values, is given in table 1, page 22.

Observations of A. Loewy, J. Loewy, and L. Zuntz, 1897.—In connection with their studies in the Alps, A. Loewy, J. Loewy, and L. Zuntz made several experiments in Berlin on the treadmill in the Landwirtschaftliche Hochschule.[2] Two experiments were made with A. Loewy, three with J. Loewy, and five with L. Zuntz. A 6.6 kilogram dry gas-meter was carried by the subject on his back and connected with the Löb valve attached to the mouthpiece. The nose was closed with a clamp. For the experiments made with A. Loewy, a base-line was used which was founded upon earlier observations. The resting values for J. Loewy and L. Zuntz were determined presumably with the subject sitting. No statement is made as to whether the subjects were in a post-absorptive condition or not. Certain experiments were also made at Col d'Olen, in which the subject likewise carried the dry gas-meter, but for these experiments the resting values were obtained with the subject in a lying position. The results for the observations with the subject walking on a level are summarized in table 1, page 22.

Observations of L. Zuntz, 1899.—In his observations regarding the gaseous-exchange of bicycle-riders, Leo Zuntz included a number of experiments made on the treadmill in the Landwirtschaftliche Hochschule.[3] The statement is made that the treadmill had an inclination of approximately 1 degree. Of special interest in these observations is the fact that Leo Zuntz paid particular attention to the influence of speed upon the gaseous metabolism, varying the rate of walking from

[1]Schumburg and Zuntz, Archiv f. d. ges. Physiol., 1896, **63**, p. 461.

[2]A. Loewy, J. Loewy, and L. Zuntz, Archiv f. d. ges. Physiol., 1897, **66**, p. 477.

[3]L. Zuntz, Untersuchungen über den Gaswechsel und Energieumsatz des Rad ahresHirschwald, Berlin, 1899.

53.45 meters per minute to 145.53 meters per minute. In the treadmill experiments the stationary wet gas-meter was used and consequently the subject was not obliged to carry an excessive load. The author discusses the absence of wind-resistance and points out that at the forced speeds, the treadmill ran so irregularly that it was frequently necessary for him to run two or three steps. The research is especially worthy of note as representing an attempt to secure unusual accuracy, although one could wish that the experiments had been made with the subject in the post-absorptive condition. An abstract of the results obtained at the different speeds is recorded in table 1, page 22.

Observations of Setschenow and Schaternikow, 1900.—Setschenow and Schaternikow[1] report a research made at the physiological institute of the University of Moscow, which included six walking experiments, the length varying from 64 to 75 minutes. Three of these experiments were preceded by a preliminary period of 6 to 9 minutes in which the subject stood. Basal values were obtained in two additional experiments with the subject at complete rest. In the walking periods the subject, who was the fireman of the institution, walked back and forth in the courtyard, the speed averaging 62.47 meters per minute; the distance walked in each experiment was usually 4,455 meters. All of the experiments were made 3 to 4 hours after a light breakfast of white bread and tea. As the data given are unfortunately insufficient for computing the values per horizontal kilogrammeter and do not lend themselves to tabular presentation, this research is not included in table 1.[2]

Observations of Frentzel and Reach, 1901.—In studying the influence of an unbalanced diet upon muscular work, Frentzel and Reach made a number of observations with the subject walking on the Zuntz treadmill in the level position in the Landwirtschaftliche Hochschule in Berlin.[3] The rate of walking varied from 31.39 to 80.15 meters per minute. The resting metabolism was determined with the subject lying upon a couch, but both the resting and walking experiments were made with food in the stomach. Resting experiments were made on 16 days with subject F and on 12 days with subject R. A considerable number of resting experiments were made prior to the walking period and on days other than the walking days. Durig has criticized the experiments as showing unusually large fluctuations in the energy required per horizontal kilogrammeter. A summary of the results is given in table 1, page 22.

Observations of Zuntz and Schumburg, 1901.—In their extensive research on the physiology of walking, Zuntz and Schumburg made

[1]Setschenow and Schaternikow, Le Physiol. Russe, 1900, **2**, p. 44.

[2]War conditions make it impracticable for me to communicate with my personal friend, Professor Schaternikow, regarding the figures in this research. As they stand, if a body-weight is assumed and a resting base-line deducted, values representing only about 50 per cent of those found in other published researches are obtained.—F. G. B.

[3]Frentzel and Reach, Archiv f. d. ges. Physiol., 1901, **83**, p. 477.

numerous observations of the respiratory exchange of two students, B and P.[1] The experiments were made in Zuntz's laboratory and the treadmill was used. In most of the experiments the subjects carried the German army equipment with a considerable load, the maximum weight of the load being 31.5 kilograms. In some of the experiments they carried no load, and it is these latter experiments with which we are chiefly concerned. The basal values were obtained with the subject lying upon a sofa. Both the resting and walking experiments were made after the subject had taken a light breakfast. The usual correction for the slight elevation of the treadmill is considered. The experiments were so adjusted that both subjects could walk at the same time upon the treadmill and two complete sets of respiration apparatus, including gas-meters, were employed. The energy per horizontal kilogrammeter is given in table 1, page 22.

Observations of Durig and Zuntz, 1904.—Observations on the metabolism during walking on a horizontal level were carried out in Vienna, Col d'Olen, and Capanna Margherita by Durig and Zuntz, and their results were published in 1904.[2] The dry gas-meter and the mouthpiece, valves, and nose-clamp were employed. The resting experiments were made every morning with the subject in bed, except when a study was made of the after-effect of work. Some of the resting values used for experiments with Zuntz as a subject were taken from the published results of a previous research. Both the resting and walking experiments were without food. After the basal values obtained with the subject lying in bed had been deducted, the energy per horizontal kilogrammeter was computed and is given in table 1, page 22.

Observations of Caspari, 1905.—In his study of vegetarianism, Caspari[3] had an opportunity of studying the metabolism of two competitors in a walking-match from Dresden to Berlin, one of whom was a vegetarian and the other subsisted on a mixed diet. The experiments were made upon a treadmill in Zuntz's laboratory and presumably the Zuntz technique was carried out in all details. Striking differences in the gait of the two subjects were noted. One of the subjects, K. M., won the match, proving himself a particularly efficient walker. The basal values were obtained while the subject was lying in absolute rest. The walking experiments were made with food, and probably the rest experiments also, although no statement is given in regard to the food with the rest experiments. After the basal values had been deducted from the values found with the treadmill, the energy per horizontal kilogrammeter was computed and is given in table 1, page 24.

Observations of Zuntz, Loewy, Müller, and Caspari, 1906.—In connection with the classical research on the physiology of man in high

---

[1] Zuntz and Schumburg, Studien zu einer Physiologie des Marsches. Hirschwald, Berlin, 1901.
[2] Durig and Zuntz, Travaux de l'année 1903, Laboratoire scientifique international du Monte Rosa, Turin, 1904, p. 65; also Archiv f. Anat. u. Physiol., Physiol. Abth., 1904, Suppbd., p. 417.
[3] Caspari, Archiv f. d. ges. Physiol., 1905, **109**, p. 473.

altitudes, which was made in the Alps, Zuntz, Loewy, Müller, and Caspari[1] carried out a series of resting and horizontal walking experiments in Berlin. The resting experiments were all made with the subject lying in bed in the morning before taking food. The experiments on horizontal walking were presumably without food and hence it is permissible to deduct the basal values directly to compute the energy per horizontal kilogrammeter. (See table 1, page 24.) The large wet gas-meter was doubtless employed in the Berlin experiments, together with the rest of the Zuntz technique. The walking experiments on the treadmill were as follows: With Waldenburg, 9; with Kolmer, 4; with Caspari, 5; with Müller, 6. The especially high values found with Kolmer in this research are commented upon at length by Durig.[2]

Observations of Durig, 1906.—In connection with an expedition in the Alps, Durig and his wife were the subjects of a number of resting and horizontal walking experiments.[3] Both the basal and walking experiments were made with the subject in the post-absorptive condition, that is, several hours after the taking of food. The dry gas-meter was used and the Zuntz technique. 18 resting experiments and 8 horizontal walking experiments were made with Durig and 11 resting experiments and 6 walking experiments with Frau Durig, all of these being in the mountains. In addition the average value is given for a number of horizontal walking experiments with Frau Durig in Vienna. Special comment should be made of the extraordinarily heavy apparatus—16.5 kilograms—carried by Frau Durig, who weighed but 45.7 kilograms. The basal values have been deducted from the values obtained in the walking experiments and the energy per horizontal kilogrammeter has been computed; this is given in table 1, page 24.

Observations of Durig, Kolmer, Rainer, Reichel, and Caspari, 1909.—The extraordinary care which characterizes all of the researches of Durig is manifest in his classical contributions on the physiology of man in the Alps; of particular value are his keen criticisms and summation of earlier research.[4] Indeed, nowhere do we find so sharp a recognition of all of the fundamental tenets of careful experimentation in gaseous metabolism, and particularly in the physiology of walking with special reference to the physiology of man in high altitudes, as in this series of contributions from Durig's laboratory. The observations were all made with the portable dry gas-meter which, with the equipment, weighed 11 kilograms. The experiments were made in the morning, either without food or after taking a cup of weak tea. 32 observations were made on a level road 200 meters long in Vienna and 12 observa-

[1]Zuntz, Loewy, Müller, and Caspari, Höhenklima und Bergwanderungen in ihrer Wirkung auf den Menschen, 1 Aufl., Berlin, 1906.

[2]Durig, Denkschriften d. math.-natur. Kl. d. kaiserl. Akad. der Wissensch., 1909, **86**, pp. 253 and 254.

[3]Durig, Archiv f. d. ges. Physiol., 1906, **113**, p. 213.

[4]Durig, Kolmer, Rainer, Reichel, and Caspari, Denkschrift. d. math.-natur. Kl. d. kaiserl. Akad. der Wissensch., 1909, **86**, p. 242.

tions were made on the Semmering. Durig discusses carefully all of the factors which should be taken into consideration in experiments of this nature and in the interpretation of their results. Of especial interest is his discussion of the suitable base-line to be deducted from the values found in the walking experiments. It should be noted that he adheres to the basal values found with the subject lying, as he considers the evidence in regard to the standing position wholly inadequate. His final computations for the energy required per horizontal kilogrammeter are given in table 1, page 24.

Observations of Amar, 1910.—In a research on the metabolism of Arabs,[1] Amar made numerous walking experiments with 15 subjects, who ranged in weight from 59 to 78 kilograms. The experiments were not made with the subject in the post-absorptive condition and loads weighing from 45 to 60 kilograms were carried. The Thiry metallic valve and a dry gas-meter were used. The author gives a very inadequate description of his technique. It appears, however, that Amar probably calculated the heat output of his subjects from the energy of the food and obtained an approximate control of his results by computing the heat output from the actual determinations of the oxygen intake and the calorific value of oxygen. Averages computed from the individual figures given by the author are included in table 1, page 24.

Observations of Amar, 1911.—In a series of walking experiments reported in 1911, Amar[2] used Thiry respiration valves which were connected with a dry gas-meter. The apparatus was placed upon a table, which was pushed behind the subject as he walked, and samples were withdrawn and analyzed, apparently for oxygen alone. The experiments were made in the morning, 10 or 12 hours after the taking of food. Control experiments were made with the subject standing and also with the subject sitting, Amar noting an increase in the metabolism during standing as compared with sitting. His computations are based upon the increase in energy expenditure while walking above that in a state of repose. Especial attention is given in his discussion to the variations in the load and the economic value of the rate of walking. The experiments have been criticized by Brezina and Kolmer,[3] who protest against the lack of information as to the details of the experiments and the technique and state that the barometric pressure, temperature, and carbon-dioxide output were apparently not taken into consideration. An abstract of Amar's results is given in table 1, page 24.

Observations of Brezina and Kolmer, 1912.—A series of walking experiments was made by Brezina and Kolmer in Durig's laboratory in Vienna.[4] In one set of experiments the subject carried on his back a

[1]Amar, Le rendement de la machine humaine, Paris, 1910; also, Le moteur humain, Paris, 1914, pp. 493 and 494.
[2]Amar, Journ. de Physiol. et de Pathol. gen., 1911, **13**, p. 212.
[3]Brezina and Kolmer, Biochem. Zeitschr., 1912, **38**, p. 132.
[4]*Ibid*, p. 129.

dry gas-meter and the ordinary equipment was used, including the mouthpiece and valves. This, with additional weights, made a load of 11 kilograms. In one set of the experiments in which heavier loads were used, the gas-meter was carried by the subject, but in later experiments the meter was carried by an assistant who walked behind the subject. All of the experiments were made on a path near the laboratory and after the subject had taken a cup of tea with sugar. The authors maintain that the last heavy meal was taken 12 hours previous to the experiment, and that the influence of the ingestion of food was therefore eliminated. In computing the results, a basal value of 1,083 gram-calories per minute was assumed for the subject. The authors point out that this is, to a certain degree, arbitrary. It should be noted that some of the experiments are considered less accurate than the others, owing to difficulties with the gas-meter. Special emphasis is laid upon variations in load and in the rate of walking. In a subsequent paper Brezina and Reichel[1] review the earlier paper of Brezina and Kolmer and make certain corrections in the values. These corrected values are used by us in our summation of the results of Brezina and Kolmer in table 1, pages 24 and 26.

Observations of Douglas, Haldane, Henderson, and Schneider, 1913.—In connection with researches carried out on Pike's Peak by Douglas, Haldane, Henderson, and Schneider, a number of observations were made on Douglas, both at Oxford and on Pike's Peak.[2] The special form of respiration apparatus devised by Douglas was used, consisting of a mouthpiece and a pair of valves connected by tubing with a large rubber bag carried on the back of the subject. The experiments were made with the subject lying in bed, in a standing position, and walking on a horizontal plane at the rate of 2 to 5 miles an hour. The basal values were assumed to be those measured when the subject was standing quiet with the muscles relaxed. Apparently some of the lying experiments were made with the subject in a post-absorptive condition, while the standing and walking experiments were made after food had been taken. No attention was paid to the character or amounts of food eaten and the possible influence upon the measurements, as the observations were not made primarily for the purpose of studying the absolute metabolism. A summary of the results is given in table 1, page 26.

Observations of Brezina and Kolmer, 1914.—To carry out the plan conceived by Durig of studying the metabolism during walking under every possible condition and to complete their own earlier experiments, in which they studied the influence of speed and load during walking on a horizontal path, Brezina and Kolmer made a second research, in which they studied the influence of the work of ascent upon the metabo-

[1] Brezina and Reichel, Biochem. Zeitschr., 1914, **63**, p. 170.
[2] Douglas, Haldane, Henderson, and Schneider, Phil. Trans. Roy. Soc. London, 1913, ser. B, **203**, p. 185.

lism.[1] Numerous experiments were carried out in the Hoschschule f. Bodenkultur in Vienna, with the treadmill both horizontal and inclined, and with and without load. Presumably the wet gas-meter was used. In the load experiments the subject carried a knapsack with weights in it. In the 15 experiments with the treadmill horizontal, the rate of walking ranged from 30.1 to 55.2 meters per minute, the speed being low to correspond with the rate of walking in the experiments with the treadmill inclined. Brezina himself was the subject. The experiments were made in the forenoon, 1½ hours after the taking of a cup of sweetened tea. The base-line used was probably the values obtained with the subject lying down, and the Zuntz method for determining the respiratory metabolism was employed. The caorlies required per horizontal kilogrammeter are given in table 1, page 26.

Observations of Galeotti, Barkan, Giuliani, Higgins, Signorelli, and Viale, 1914.—On an expedition to Col d'Olen on Monte Rosa in 1913 Galeotti, Barkan, Giuliani, Higgins, Signorelli, and Viale made a number of observations on the gaseous metabolism of four individuals while the subjects were walking on a level.[2] Since basal values were obtained in only one instance, it was necessary to assume these for the other subjects. The Douglas bag and the Siebe-Gorman valves were used, except in one experiment when the Tissot valves were substituted. Strict attention was given to the use of food, certain tests being specifically made after breakfast. The experiments which are reported here, however, were made with the subjects in the post-absorptive condition. An abstract of the values for the horizontal kilogrammeter is given in table 1, page 26.

SUMMARY OF RESULTS OF PREVIOUS OBSERVATIONS.

In an attempt to arrange in chronological order a mathematical expression of the values on a comparable basis, we have gathered together all of the literature available on horizontal walking and summarized the results of previous researches in table 1. In some of the work, particularly in the earlier observations, certain assumptions were essential. These assumptions, which were based upon careful analyses of all of the experiments, upon deductions drawn from the experience of this laboratory in metabolism experiments, and upon known and recognized errors in technique are, we believe, justifiable and in all probability are not greatly in error. The table gives the name of the author and the date of reporting the results of the research; the name or initials of the subjects of the walking experiments; the conditions under which the experiments were made; the method of measuring the respiratory exchange; the kind of walking, *i. e.*, in a room, out of doors, or on a

---

[1]Brezina and Kolmer, Biochem. Zeitschr., 1914, **65**, p. 16.

[2]Galeotti, Barkan, Giuliani, Higgins, Signorelli, and Viale, Reale Accademia dei Lincei, Rome, 1914, and Arch. d. Fisiol., 1914, **12**, p. 277.

TABLE 1.—*Historical summary of walking*

Author, date of publication, and subject.	Condition during walking.	Method of measuring respiratory exchange.	Kind of walking.
Smith, 1859:			
Smith	6 hours after food (?).	Mask for resting; mouthpiece for walking; spirometer carried.	Indoors, 11 yds. in each direction.
Gruber, 1891:			
Gruber	5 to 6 hrs. after food.	Tube in mouth; absorption apparatus in knapsack carried on breast.	In room, back and forth.
Katzenstein, 1891:			
Kohansky	With food (?)	Zuntz and Lehmann	Zuntz treadmill.
Krzywy			
Wellnitz			
Zimm			
Sondén and Tigerstedt, 1895:			
F. A. W.	With food	Respiration chamber	In chamber
G. J.			
L. B.			
F.			
Schumburg and Zuntz, 1896:			
N. Zuntz	Not stated	Zuntz and Geppert; dry gas-meter on back.	Zuntz treadmill.
Schumburg			do
N. Zuntz			In room.
A. Loewy, J. Loewy, and L. Zuntz, 1897:			
A. Loewy[7]	do	do	Zuntz treadmill.
J. Loewy[7]			
L. Zuntz[7]			
A. Loewy[8]	A few hours after light, liquid breakfast.	do	Small plateau in front of hotel.
J. Loewy[8]			
L. Zuntz[8]			
L. Zuntz, 1899:			
L. Zuntz	Moderate breakfast.	Zuntz; wet gas-meter near treadmill.	Zuntz treadmill.
Frentzel and Reach, 1901:			
Frentzel	With food	Zuntz	do
Reach			
Zuntz and Schumburg, 1901:			
B	After a light breakfast.	Zuntz and Geppert	do
P			
Durig and Zuntz, 1904:			
Durig[11]	Without food (?)	Zuntz and Schumburg; dry gas-meter on back.	Free path, outdoors (?).
Durig[8]			
N. Zuntz[8]			
Durig[13]		do	In hut
N. Zuntz[13]			

[1]The summarized data in this table are based on published material cited on pp. 11 to 21.
[2]Calculated from the data available, assuming a respiratory quotient of 0.85 and 1,609.35 meters per mile.
[3]Computed with several necessary assumptions, *i. e.*, length of step, 0.680 meter; number of steps, 80 per minute for second figure as well as for the first; respiratory quotient, 0.85.
[4]Values computed by Durig (Denkschrift. d. math.-natur. Kl. Akad. Wissensch., 1909, **86**, p. 242), including correction for angle of ascent as indicated by Katzenstein.
[5]All heat values computed by Durig (loc. cit., p. 256), assuming respiratory quotient of 0.85. Corresponding figures assuming a quotient of 0.75 were: 0.559, 0.373, 0.515, and 0.358.

experiments on horizontal plane.[1]

Resting value.	Average weight moved.	Distance per minute.		Heat computed per horizontal kilogrammeter.	
		Range.	Average.	Range.	Average.
	kilos.	*meters.*	*meters.*	*gm.-cals.*	*gm.-cals.*
Sitting, 6 hrs. after food.......	92.08	....	53.64	....	[2]0.407
			80.46	....	[2].468
Sitting, 5 to 6 hrs. after food...	72.00	....	54.40	....	[3].360
			54.40	....	[3].356
Standing, leaning against treadmill; with food (?).	55.53	56.00– 92.00	74.48	....	[4].526
	58.00	51.00– 75.00	61.80	....	[4].786
	75.16	58.00– 71.00	63.50	....	[4].554
	57.30	64.00– 66.00	65.05	....	[4].426
Sitting, with food............	62.73	58.70– 62.40	60.60	0.506–0.506	[5].506
	78.25	....	50.10	....	[5].337
	70.09	62.20– 67.90	65.10	.503– .427	[5].465
	68.77	....	32.00	....	[5].324
Sitting....................	80.00	....	51.20	....	[6].678
	88.20	....	42.00	....	[6].616
	80.00	47.80– 52.40	50.10	[6].606– .803	[6].718
"Ruhewert"................	72.60	61.60– 62.40	62.00	.635– .705	.670
Sitting....................	81.10	59.00– 62.80	60.90	.511– .560	.535
....do....................	80.00	54.50– 59.20	56.40	.446– .636	.570
Lying, without food..........	72.60	61.80– 70.21	67.10	.651– .724	.681
	81.10	59.40– 62.04	60.54	.759– .877	.821
	80.30	63.21– 67.33	65.24	.548– .712	.616
"Ruhewert"................	72.94	53.45– 59.35	56.76	[9].538– .561	[9].554
		92.41–103.40	98.67	[9].621– .693	[9].653
		135.74–145.53	140.11	[9]1.015–1.168	[9]1.072
Lying, with food............	87.10	57.80– 80.15	66.94	.442– .626	.527
		31.39– 39.91	35.92	.511– .620	.560
	66.40	60.28– 66.88	63.95	.507– .596	.553
		31.58– 37.23	34.58	.464– .676	.558
Lying, after light breakfast....	67.92	70.66– 89.21	76.50	....	[10].527
	72.93	58.21– 82.38	73.50	....	[10].509
Lying, without food..........	[12]91.80	95.70–111.50	99.60	.474– .571	.527
	[12]73.80	57.34– 95.42	85.56	.448– .681	.584
	[12]82.50	78.66– 80.66	79.93	.574– .714	.663
.....do....................	[12]74.90	66.26– 91.59	84.21	.633– .699	.668
	[12]78.70	60.03– 66.67	62.86	.742– .796	.774

[6]Values given by Durig (loc. cit., pp. 248 and 261). Figures for treadmill experiments were corrected by Durig for angle of ascent.

[7]Experiments conducted at Berlin. [8]Experiments conducted at Col d'Olen.

[9]All heat values calculated by Durig (loc. cit., p. 270).

[10]Corrected by authors for slight elevation of treadmill. Values for load experiments may be found on pages 247, 255, and 278 of the original publication, but not corrected for angle of ascent

[11]Experiments conducted at Vienna.

[12]Not given by authors; these weights were accordingly computed from other data which had been obtained by means of the body weight. [13]Experiments conducted at Capanna Margherita.

TABLE 1.—*Historical summary of walking*

Author, date of publication, and subject.	Condition during walking.	Method of measuring respiratory exchange.	Kind of walking.
Caspari, 1905:			
K. M.	With food	Zuntz	Zuntz treadmill
J. B.	do	do	do
Zuntz, Loewy, Müller, and Caspari, 1906:			
Waldenburg Kolmer Müller Caspari	Without food	Zuntz and Geppert; presumably wet gas-meter.	Zuntz treadmill
Durig, 1906:			
Frau D.[2] Frau D.[3] Durig[3]	Without food	Zuntz and Schumburg; dry gas-meter on back.	Free path
Durig,[5] Kolmer, Rainer, Reichel, and Caspari, 1909:			
Durig[2]	Without food, or after cup of weak, sweetened tea.	Zuntz; dry gas-meter on back.	Outdoors
Durig[6]	do	do	do
Kolmer[2]	do	do	do
Rainer[2]	do	do	do
Reichel[2]	do	do	do
Reichel[6]	do	do	do
Amar, 1910:			
Arabs	With food	Chauveau valve; dry gas-meter.	Circular path outdoors.
Amar, 1911:			
S. L.	10 to 12 hrs. after food.	Chauveau valve; dry gas-meter; apparatus on table moved with subject.	In room, 11 meters in each direction.
Brezina and Kolmer,[9] 1912: Brezina	12 hrs. after food, or at least 2 hrs. after cup of sweetened tea.	Dry gas-meter carried by assistant in first series of experiments, and in last 3 series; in 2d and 3d series, subject carried meter.	Level path outdoors, involving turns.

[1]Average values as corrected by the authors.
[2]Experiments conducted at Vienna.
[3]Experiments conducted at Sporner Alps.
[4]Not given by the author, but computed from other data in which the body weight was involved. There is a possible error of about 2 kilograms in this weight.
[5]The data from these experiments have been grouped for this summary, with special attention to place and rate of walking.
[6]Experiments conducted at Semmering.

experiments on horizontal plane—Continued.

Resting value.	Average weight moved.	Distance per minute.		Heat computed per horizontal kilogrammeter.	
		Range.	Average.	Range.	Average.
	kilos.	*meters.*	*meters.*	*gm.-cals.*	*gm.-cals.*
Lying	63.18	134.90–142.90	139.40	.952–1.018	.979
	63.47	172.00–182.60	177.30	1.154–1.184	1.169
.....do	65.35	122.20–135.70	131.70	.906–1.020	.972
Lying, without food	74.08	44.14– 78.85	60.20	....	[1].636
	85.10	37.00– 48.45	43.16	....	[1].845
	87.40	73.29– 86.52	81.17	....	[1].613
	81.95	67.47– 82.69	76.76	....	[1].643
Lying, without food	[4]57.50	....	65.00	....	.604
	63.38	66.07– 79.63	71.90	.629– .691	.668
	79.25	88.49– 99.63	95.44	.620– .660	.641
Lying	76.20	72.30–102.30	90.10	.517– .559	.539
		116.6	116.60	0.628	.628
		126.0	126.00	.735	.735
	76.10	141.8	141.80	.854	.854
		152.5	152.50	1.023	1.023
.....do	76.30	100.70–103.20	102.20	0.566–0.587	0.573
	76.50	105.40–110.30	107.90	.622– .636	.629
.....do	94.20	49.2	49.20	0.542	.542
		62.40– 69.20	66.30	0.535–0.591	.562
		100.00–105.20	102.50	.635– .659	.648
.....do	75.40	47.2	47.20	0.538	.538
		76.90– 91.30	87.20	0.533–0.584	.567
		115.8	115.80	0.772	.772
		129.5	129.50	.954	.954
.....do	100.30	59.30–100.80	88.20	0.510–0.583	.548
.....do	95.45	93.20– 99.20	96.30	.563– .591	.573
	95.45	103.50–103.90	103.70	.641– .659	.650
"Repos" with food	113.80	72.00– 90.00	79.20	.257– .402	[7].308
	134.10	72.00– 80.40	74.80	.310– .335	[7].323
Standing or sitting	66.00	32.40– 89.83	59.43	.315– .577	[8].410
	73.30	30.33– 78.08	55.06	.365– .535	[8].422
"Erhaltungsumsatz" of 1083 gram-calories.	70.10	46.10– 72.20	62.40	.4844– .6033	[9].534
	70.90	81.80– 98.60	88.90	.5615– .5985	.574
	69.90	103.10–115.80	111.20	.7266– .7684	.743
	70.50	120.10–131.20	125.20	.8172– .8777	.846
	70.50	140.60–141.00	140.80	.9347–1.0070	.971

[7]Averages computed from results given by the author for 15 different subjects. The results are grouped for the two loads carried.

[8]All heat values computed from the oxygen increment during walking as given by the author and with an assumed respiratory quotient of 0.85. Assuming a quotient of 0.75, the results for the two series are: range 0.307 to 0.562; average, 0.400; range 0.356 to 0.521, average 0.411.

[9]The results in each of these series have been grouped for this summary according to the rates of walking, the limit of the first group being set at about 80 meters in agreement with the treatment given the material in the original publications. The values for distance and calories are given as corrected by Brezina and Reichel.

TABLE 1.—*Historical summary of walking*

Author, date of publication, and subject.	Condition during walking.	Method of measuring respiratory exchange.	Kind of walking
Brezina and Kolmer,[1] 1912 (continued): Brezina	12 hrs. after food, or at least 2 hrs. after cup of sweetened tea.	Dry gas-meter carried by assistant in first series of experiments, and in last 3 series; in 2d and 3d series, subject carried meter.	Level path outdoors, involving turns.
Do	do	do	do
Do	do	do	do
Do	do	do	do
Do	do	do	do
Douglas, Haldane, Henderson and Schneider, 1913: Douglas	With food	Douglas bag	Room in laboratory at Oxford; circular path.
Do	do	do	Railway track, Pike's Peak, back and forth.
Do	do	do	Grass track, Oxford, back and forth.
Brezina and Kolmer, 1914: Brezina	1½ hrs. after cup of sweetened tea.	Zuntz	Zuntz treadmill
Galeotti, Barkan, Giuliani, Higgins, Signorelli, and Viale, 1914: Barkan	Without food	Douglas bag	Half indoors, half outdoors, with a turn (all indoors in bad weather.)
Higgins		do	
Signorelli		do	
Viale		do	

[1]The results in each of these series have been grouped for this summary according to the rates of walking, the limit of the first group being set at about 80 meters in agreement with the treatment given the material in the original publications. The values for distance and calories are given as corrected by Brezina and Reichel.

[2]The body-weights in all the series with Douglas have been computed from the distance and the total oxygen and the oxygen per kilogram per meter as given by the authors. The subject's naked weight at Oxford was about 63.5 kilograms; at Pike's Peak, 60.8 kilograms.

experiments on horizontal plane—Continued.

Resting value.	Average weight moved.	Distance per minute.		Heat computed per horizontal kilogrammeter.	
		Range.	Average.	Range.	Average.
	kilos.	*meters.*	*meters.*	*gm.-cals.*	*gm.-cals.*
"Erhaltungsumsatz" of 1083 gram-calories.	81.60	37.40– 73.30	53.10	0.4709–0.5278	[1].489
	80.80	78.20– 84.20	81.50	.5040– .5411	.520
	81.00	92.80– 94.50	93.40	.6088– .6213	.616
	80.50	105.7	105.70	0.7107	.711
	81.00	118.1	118.10	.9281	.928
	81.00	125.60–129.00	127.30	0.9626–0.9720	.967
.....do.....................	91.20	43.50– 77.70	62.00	.4502– .5716	[1].506
	91.30	84.60– 94.90	91.00	.5651– .5933	.581
	91.10	104.70–105.10	104.90	.7232– .7982	.761
	92.25	115.80–115.80	115.80	.9121– .9122	.912
.....do.....................	103.50	32.80– 74.00	54.80	.4766– .5883	[1].529
	103.60	86.00– 90.60	88.30	.5439– .6436	.594
	103.20	100.0	100.00	0.7256	.726
	103.00	111.4	111.40	.9143	.914
.....do.....................	112.60	37.00– 76.70	55.00	0.5433–0.6391	[1].577
	113.00	78.10– 82.20	80.20	.5450– .6778	.611
	113.00	89.90– 94.70	92.30	.8143– .8796	.847
.....do.....................	123.00	48.60– 68.90	58.80	.5858– .5884	[1].587
	123.00	90.9	90.90	0.7747	.775
Standing, with food...........	[2]72.45	[3]52.03– 54.18	[3]53.38	[3]0.366 –0.448	[3].402
	72.77	77.25– 82.88	81.00	.440 – .490	.460
	73.76	102.73–107.83	105.95	.523 – .549	.531
	72.73	119.90–121.77	120.97	.638 – .682	.656
	72.78	134.65–137.87	136.26	.889 – .907	.898
....do.....................	[2]70.71	[3]51.77– 54.98	[3]53.64	[3].524 – .607	[3].562
	70.48	77.52– 81.55	79.66	.568 – .634	.600
	70.70	102.73–111.32	108.09	.713 – .862	.789
	70.88	112.67–116.15	114.53	.768 – .897	.833
	70.89	132.77–132.77	132.77	.919 – .964	.942
....do.....................	[2]72.94	[3]53.12– 54.98	[3]53.91	[3].547 – .609	[3].571
	72.59	79.13– 84.50	82.88	.588 – .600	.595
	73.77	105.42–111.58	108.36	.704 – .873	.776
	74.36	120.43–126.33	123.38	.770 –1.009	.897
	73.42	130.63–139.48	136.26	.978 –1.126	1.066
"Ruhewert"..................	71.60	31.00– 51.70	46.10	.50 – .56	[4]0.53
	83.80	51.40– 55.20	53.80	.48 – .56	[4] .50
	93.00	49.40– 52.40	51.10	.42 – .55	[4] .50
	104.00	30.1	30.10	0.51	[4] .51
Lying, without food..........	79.30	....	86.70	0.570 –0.395	[5]0.448
	68.00	....	65.00	....	[5] .550
	69.50	....	86.70	.374 – .398	[5] .386
	78.50	....	86.70	....	[5] .375

[3]It was necessary to convert the distances from miles to meters and to compute the heat from the oxygen consumption.

[4]Averages of individual heat values given for the groups in the original publication.

[5]In computing all heat values for Barkan and Viale, the value for lying without food was assumed to be represented by 255 c.c. of oxygen; for Signorelli, 225 c.c. of oxygen. In one experiment with Higgins, a corresponding value of 203 c.c. of carbon dioxide and of 265 c.c. of oxygen was obtained. The weight of the clothing and the Douglas bag was about 7 kilograms in each case.

treadmill; the basal or resting value for the individual subjects; the total weight of the material moved in a horizontal direction, including the weight of the body, clothing, apparatus, and any supplementary weight which the subject may have carried; the distance walked per minute; and finally, the calories per horizontal kilogrammeter.

The speed of the walking, which is shown by the distance walked per minute, is a factor of considerable importance; the range and average are therefore both given. Whenever there is a great difference in the speed for the same subject, a special line is assigned to it. Wide variations are shown in the average distance walked per minute in the several researches, the figures ranging from 32 meters in the Sondén and Tigerstedt experiments published in 1894 to 177.3 meters in an experiment by Caspari reported in 1905.

As a result of a careful analysis of the earlier literature of Durig and of Zuntz and his co-workers, the unit adopted for expressing the work of forward progression is the calories required to move 1 kilogram 1 meter or, as we shall here designate it, the calories per horizontal kilogrammeter. The range and average are both given for these values, but the average values have here the greater significance, and it is the last column of the table which we shall particularly consider. Examining these data, we find that they range from 0.308 gram-calorie in the series of experiments made by Amar and reported in 1910 to 1.169 gram-calories in the experiment by Caspari published in 1905. Considering the varied technique, there is, on the whole, a rather remarkable agreement of the values found for the movement of 1 kilogram of body-weight per meter in a horizontal direction, particularly when we consider those values obtained at moderate walking speed.

Comparing the data for the average distance walked per minute and those for the average calories per horizontal kilogrammeter, we find that the rate of walking has a considerable influence upon the results and that the higher values are invariably found with the greater speeds, although the reverse is by no means true. In general, when the rate of walking does not exceed 80 to 90 meters per minute, the values lie between 0.3 and 0.7 gram-calorie, with a distinct tendency for them to approach 0.55 gram-calorie. This value has been especially considered by Durig in his admirable review of the literature of this subject. It is clear, then, that we have here to do with an intimate relationship between the rate of walking and the expenditure of energy required to move 1 kilogram 1 meter in a horizontal direction, and that the superimposed load has relatively little influence upon the results.

METHODS AND APPARATUS FOR STUDIES OF MUSCULAR WORK.

Judging from the results as published in the earlier literature and summarized in the preceding section, there is apparently little choice as to the various methods of study. A large majority of the observations have been made with the Zuntz respiration apparatus or some of its modifications; it is obvious that any criticisms applying to this apparatus affect greatly the averages of the values obtained with it. While the construction of the Zuntz apparatus and the various types of valves, particularly the later form of valve used by Durig, is such as to eliminate resistance as far as possible, nevertheless the employment of this type of apparatus for studying muscular work is distinctly open to criticism.

The use of a wet gas-meter of the size ordinarily employed with the Zuntz respiration apparatus may be seriously objected to for muscular-work experiments, since in these experiments the volumes of expired air may exceed 80 or 90 liters per minute. The calibration of such a meter at the rate of ventilation used in severe-work experiments is by no means a simple matter, the ordinary method being to allow the water in a 10-liter spirometer to flow out and draw the air in after it. On the ordinary Elster gas-meter 10 liters correspond to one or at most two revolutions of the drum, and the possibilities of error at the beginning and the end in tests of this kind are obvious. Indeed, both Durig and Zuntz have recognized this difficulty and, to avoid errors in the measurement of the large volume of air expired from the lungs, have made experiments with a very large gas-meter formerly used in studies with horses. If the value obtained for the volume of air be too small (and the error, if any, would be in this direction), obviously that for the total metabolism will likewise be too small, and hence the values computed for the horizontal kilogrammeter will be too low.

The importance of knowing the energy requirement of the body for direct forward progression is so great as to justify further observations upon it, particularly if an apparatus is used in which an entirely different principle is employed for measuring the metabolism. One of the main lines of research planned for the Nutrition Laboratory is a study of muscular work in its various phases. Obviously innumerable problems, of both physiological and economic importance, can be studied with suitable apparatus. A special calorimeter has been constructed in this laboratory for research on muscular work, but it is not yet ready for actual use. Prior to experimentation with this calorimeter, it seemed important to make a number of preliminary studies of the metabolism during muscular work with the universal respiration apparatus. This apparatus had previously been used in a study of the metabolism incidental to riding a bicycle ergometer, in which it was shown that it was capable of measuring the metabolism with an oxygen consumption as high as 3 liters per minute.[1] Careful control tests of the apparatus have proved conclusively that, so far as the mechanical construction is concerned, the measurement of the carbon-dioxide production and the oxygen consumption is accurate.

As a part of the plan for studying the metabolism during the various phases of muscular work, a special type of treadmill was devised and constructed in this laboratory several years previous to the present research. Certain features of this treadmill, which will be described subsequently, make it especially applicable for use in experiments with men. Having, therefore, an exceptionally satisfactory treadmill and a respiration apparatus capable of measuring the metabolism incidental to severe muscular work, it was possible, in 1913–14, to make a study of the metabolism of a subject while he was walking on a level.

As soon as the respiration calorimeter for muscular work is ready for use, the treadmill will be placed inside this apparatus and certain of the experiments repeated. The indirect calorimetry computed from the gaseous exchange as measured by the respiration apparatus can thus be controlled by direct determinations of the energy output. This control is of particular importance, since the use of any form of respiration appliance, such as a mouthpiece or nosepieces, is open to legitimate criticism in that the use of such artificial methods of breathing, particularly with a very great ventilation of the lungs, may lead to a disturbance in the mechanics of ventilation, thus causing a disturbance in the respiratory exchange. Although the universal respiration apparatus has been carefully controlled as to the measurement of both carbon dioxide and oxygen, nevertheless if there is a disturbance in the mechanics of ventilation, as, for instance, an over-ventilation of the lungs, there may be a considerable amount of carbon dioxide exhaled that was not simultaneously produced. The retention of carbon dioxide by altered respiratory mechanics is also not improbable. By means of the studies with the respiration calorimeter, therefore, it will be possible not only to determine the metabolism by direct calorimetry, but also to obtain the gaseous exchange with free breathing without the use of either mouth or nose appliance.

It should furthermore be borne in mind that while the method of computing the calorimetry from the gaseous exchange has, according to our experience up to the present time, given highly satisfactory results with muscular repose, there is always the possibility of a disturbance in the character of the metabolism during severe muscular work and a consequent disturbance in the relationship between the gaseous exchange and total heat production. It is thus seen that the final tests with the respiration calorimeter are essential for a complete understanding of this problem. On the other hand, the previous

[1]Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913.

research with the professional bicycle rider, in which the universal respiration apparatus was employed, was so successful and the problem of the metabolism during the work of forward progression is so important that, pending the completion and testing of the special calorimeter, the study of this problem with the universal respiration apparatus and the treadmill has seemed entirely justifiable.

DESCRIPTION OF APPARATUS USED IN THIS RESEARCH.

UNIVERSAL RESPIRATION APPARATUS.

The researches of Zuntz and his co-workers have shown that in walking at a somewhat high rate of speed and carrying a load, the amount of muscular exertion required, even on a level path, is very considerable, approximating that required for bicycle riding under severe stress. Obviously, therefore, any respiration apparatus used in a study of the metabolism under these conditions must be capable of accurately measuring a maximum oxygen consumption per minute of 3,000 c.c. and a maximum carbon-dioxide production of 2,500 c.c. Fortunately the modified form of the universal respiration apparatus employed by Cathcart had already demonstrated its ability to fulfill these conditions. The form of apparatus used in this later research was therefore essentially that employed for the earlier study.[1] A general view of the apparatus with its relations to the subject and the accessory apparatus is shown in figure 1.

Since the completion of the research on the bicycle rider, various minor modifications have been made in the apparatus, chiefly with a view to facilitating operation and contributing to its accuracy. Certain other changes were also necessary to adapt it to the type of experiment planned for this research, namely, walking upon a treadmill at varying rates of speed. These changes were considered of sufficient importance for us to give here a schematic outline of the apparatus as actually employed in the research. (See figure 2.)

As will be seen from the diagram in figure 2, by turning a 3-way valve N, the subject, breathing through a mouthpiece P, can be connected with the ventilating air-current, which is kept in motion by a rotary blower. The air leaving the blower is first passed through a glass Williams bottle which serves as a safety trap against back-suction of acid. The air is next forced through two Williams bottles, each having a capacity of 2.5 liters and half filled with sulphuric acid, which removes the moisture from the air. The ventilating current is then deflected by means of the 2-way valve V^1 into either one of two

[1]Brezina and Kolmer in a recent paper from Durig's laboratory (Biochem. Zeitschr., 1914, **65**, p. 33) have questioned the accuracy of the respiratory quotients obtained with this apparatus by Benedict and Cathcart in their study of a bicycle rider. Durig in a private communication says that the method used by Benedict and Cathcart for obtaining the respiratory quotients was accurate and that the criticisms of Brezina and Kolmer were founded upon an insufficient study of the results.

carbon-dioxide absorbing systems. Each series of absorbers include two bottles filled with moist soda lime for absorbing the carbon dioxide, and also a small Williams bottle, containing sulphuric acid to absorb the moisture given up to the dry air by the soda lime. The air, which is at this point free from carbon dioxide and water, passes through the 2-way valve V^2, and after being moistened in a small Williams bottle to a comfortable degree for respiration, it continues until it passes

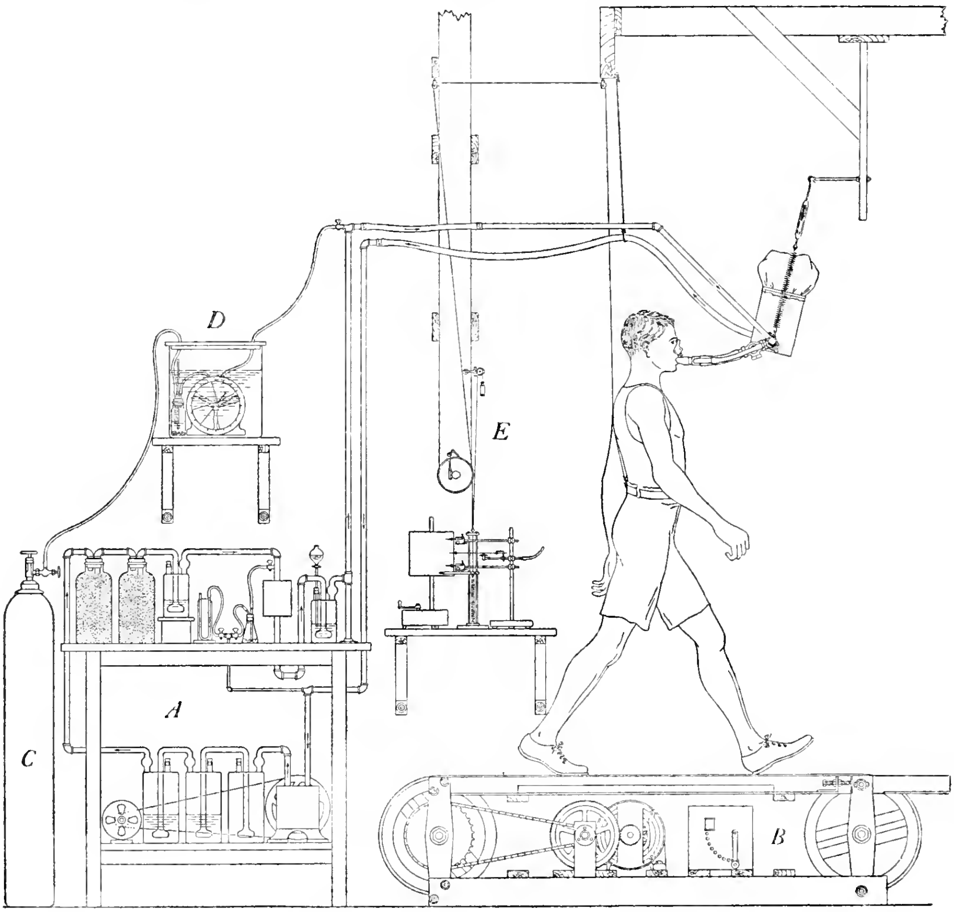

FIG. 1.—General view of apparatus used for walking experiments, with subject in position. *A*, absorption apparatus; *B*, treadmill; *C* and *D*, oxygen supply; *E*, step counter and accessory apparatus.

by the opening of the tube connected with the mouthpiece *P* and into the tension equalizer. This tension equalizer is a large copper can, over the top of which is fitted a rubber bathing-cap. From this copper can the air finally returns to the intake side of the blower, oxygen being admitted as required from a cylinder of the gas. Thus we have a complete closed-circuit system, with the rubber bathing-cap acting as a tension equalizer to compensate for changes in the volume of air as the subject breathes in and out.

The algebraic increase in weight of the soda-lime bottles and the following Williams bottle in the carbon-dioxide absorbing system gives the weight of the carbon dioxide absorbed during the experimental period. The volume of oxygen introduced may be determined from the loss in weight of a small cylinder or, as indicated in figure 1, measured by conducting it from a large cylinder through a carefully calibrated gas-meter which is immersed in water to prevent sudden fluctuations in temperature. To prove the efficacy of the soda lime as an absorbent, a part of the air current may be deflected through two petcocks and passed through a solution of barium hydroxide in a small Erlenmeyer flask. The slightest trace of carbon dioxide will produce a turbidity in the solution.

To eliminate the effect of the long dead space between the mouthpiece, *P*, and the main ventilating air-pipe, a supplementary pipe *E* is connected from a point near the mouthpiece to the main air-pipe. By this means the air-current may be deflected so that it will pass directly by the mouthpiece and within a few centimeters of the lips of the subject. The rubber tubes connecting the subject with the ventilating system are of sufficient length and flexibility to permit considerable lateral and vertical head-motion by the subject while walking, this being essential to his comfort.

In actual experimenting, before the experimental period is begun, the 3-way valve *N* is so turned that the subject breathes room air. Then, at the end of a normal expiration, the 3-way valve is again turned, connecting the subject with the main ventilating air-current as seen in the diagram. Immediately afterwards the valve *M* (which has previously been open, giving free passage of the air into the metal tee leading to the tension equalizer) is also turned, thus deflecting the air-current through the supplementary pipe *E*, so that it passes near the mouth of the subject.

Before connecting the subject with the ventilating system, the motor is started to equalize pressure throughout the system and then stopped. Sufficient oxygen is next admitted to distend the rubber bathing-cap until a slight positive pressure is observed on the manometer. On starting the blower again, the rubber bathing-cap sinks somewhat, due to the compression of the air in forcing its way through the sulphuric acid and the various absorbing-vessels. At the first inspiration the rubber cap sinks down into the can, rising again with each expiration. As the oxygen is consumed, the height to which the rubber cap fills decreases and oxygen is admitted to keep the fluctuations of the bathing-cap to approximately the same range. At the conclusion of the experiment, the valve *M* is first turned and shortly afterwards the valve *N* is also turned, always at the end of a normal expiration. At this point the experimental period is concluded so far as the subject is concerned. The motor is next allowed to run for a minute or two to sweep out completely the carbon dioxide in the system. When the motor is stopped sufficient oxygen is admitted to bring the tension to the original point; the volume of air in the system is then exactly the same as at the beginning. The carbon-dioxide absorbers and the accompanying Williams bottle are weighed and a reading taken of the amount of oxygen which has passed through the gas-meter, the data being used subsequently for computing the carbon dioxide produced and the oxygen consumed during the experimental period.

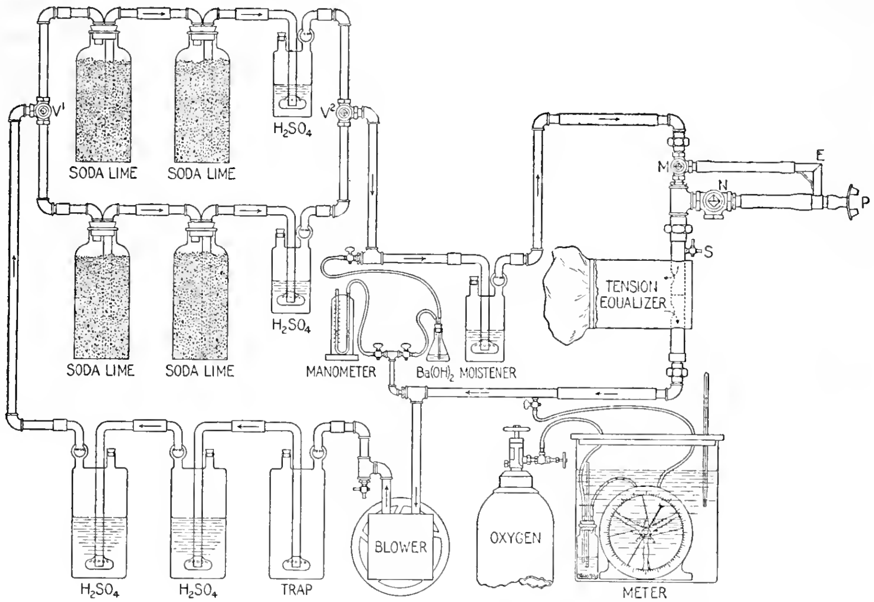

FIG. 2.—Schematic outline of universal respiration apparatus.

The general course of the ventilating current is shown by arrows. *P*, mouthpiece; *N*, 3-way valve connecting subject with ventilating current; V^1 and V^2, 2-way valves for carbon-dioxide absorbing system; *M*, valve connecting with supplementary pipe *E* for eliminating the dead-air space; *S*, petcock connection for tambour and kymograph for recording the respiration.

TREADMILL.

In many of the earlier investigations for measuring the carbon-dioxide output and oxygen consumption of a walking man, the subject has been obliged to carry a respiration apparatus upon his back or drag behind him a long tube attached to the breathing appliance. In other studies the apparatus has been pushed along behind the subject by an assistant. Obviously none of these methods are suitable for experiments in which there is rapid movement. Furthermore, while we have no desire to minimize the value of the Zuntz apparatus—an apparatus which has contributed largely to our knowledge of the physiology of man, particularly for high altitudes—it should be said that the transportation of an unwieldy gas-meter and accessory apparatus by a subject is open to serious objection. It has been shown by Zuntz and his co-workers that a subject may be trained in a relatively short time to carry such an apparatus successfully; nevertheless its transportation is at best difficult, and the method is more fitted for studies of that type of walking in which loads would normally be carried upon the back. Both Zuntz and Durig have shown that they recognize this fact, as they have made studies in which the gas-meter was not carried by the subject, and the walking was done upon a treadmill.

Several years previous to our research, Mr. E. H. Metcalf, then a member of the staff of the Nutrition Laboratory, designed a treadmill and had it constructed under his supervision in the machine-shop of the Laboratory. This treadmill was used for the first time in the research carried out in 1913–14 and the fact that it satisfactorily sustained a severe test at this time testifies to the designing ability of Mr. Metcalf and the constructive skill of Mr. W. E. Collins, the mechanician of the Laboratory. A general view of the treadmill and its disposition with regard to the other apparatus is shown in figure 1. A more detailed perspective drawing is given in figure 3.

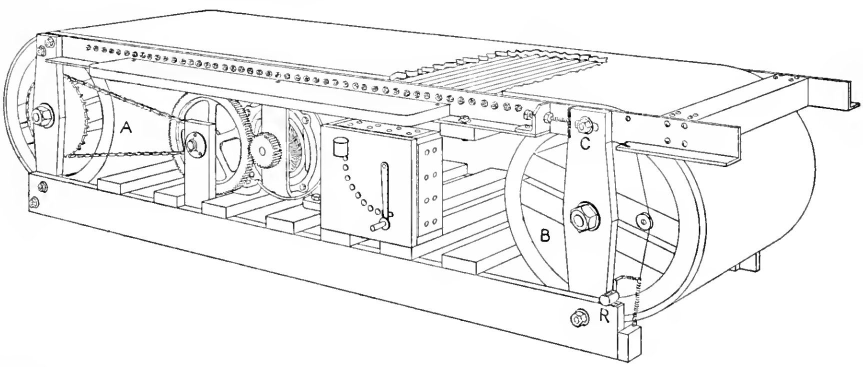

FIG. 3.—Treadmill designed by E. H. Metcalf.

The endless leather belt travels over two wooden pulleys *A* and *B*, the actuating mechanism being an electric motor. The tension on the belt may be adjusted by the bolt and nut *C*. A revolution counter is shown at *R*.

The treadmill is provided with an endless belt, 60 cm. wide, 435 cm. long, and approximately 10 mm. thick. This belt travels over two wooden pulleys, *A* and *B*, having a width of 60 cm. and a diameter of 41 cm. The pulleys are supported on ball bearings at the ends of a wooden frame. On the rear pulley is attached a sprocket-wheel, which connects with the reducing-gear actuated by a one-half horsepower electric motor. The tension on the belt may be easily adjusted by means of the screw *C*, thus preventing the belt from slipping. To support the belt between the pulleys and provide a surface for the man to walk upon, steel tubes, 46 in number, with an external diameter of 25 mm. and a length of 61 cm., are set into a steel framework, the distance between the centers of the tubes being 27 mm. These steel tubes are fitted at each end with annular steel ball bearings.

The detail of the bearings is given in figure 4, which shows the method of support on the angle frame of the treadmill. The thick belt thus rests upon a rolling, frictionless surface throughout the whole length of the space over which the man is to walk, providing a substantial, perfectly smooth path for the subject. It is impossible to feel the numerous steel rolls, as the space between them is so small. The leather belt gives a particularly satisfactory footing. The speed of the motor may be modified at will and tests may be made at rates of speed varying from less than 50 meters per minute, the equivalent of a very slow walk, to 150 meters per minute, or a rapid walk, if not, indeed, running.

Since the driving of the treadmill belt is from the rear wheel, all tendency to slip is at this point. Consequently, by counting the revolutions of the forward wheel, where no slip can possibly take place, we have an accurate measure of the total distance traveled. Upon the periphery of the forward wheel are attached two revolution counters (one on each side)[1] which can be read intermittently. One runs continuously; the other may be connected or disconnected at will. In use, the subject walks upon the treadmill for several minutes before the experimental period commences. At the exact moment of beginning the measurements of the respiratory exchange, one of the revolution counters is put in action, so that the distance covered during the period is accurately known. It is thus unnecessary to assume constancy in the revolution of the motor or to apportion the distance walked during the period from the total measurement of the revolutions of the front wheel during the entire time the subject is walking.

Considering the number of the various bearings and the size of the apparatus it produces much less noise and vibration than any treadmill that we have thus far seen. By means of adjusting screws at the forward end of the treadmill, which are not shown in figure 3, any desired elevation can be readily secured. In this research, however, the treadmill was invariably used in a perfectly level position. At the date of writing (June 1915), after two years of use, the apparatus shows no signs of wear and gives most satisfactory service.

ACCESSORY APPARATUS.

The universal respiration apparatus and the treadmill provide accurate measurements of the total carbon-dioxide production and the oxygen consumption and of the distance walked by the subject. In addition to this, certain observations are important, particularly in studying the physiology of walking, and it was therefore necessary to have some means of recording accurately the respiration, the pulse, the number of steps taken by the subject, and the height to which the body was raised with each step.

---

[1]But one of these (*R*) is shown in figure 3.

METHOD OF RECORDING THE RESPIRATION-RATE.

The rise and fall of the rubber bag or tension equalizer with each expiration and inspiration can be readily counted by an observer, thus giving an admirable index of the respiration. As a matter of fact, during the conduct of a severe-work experiment of this type, the other observations are so numerous that it is at best very difficult for an observer to concentrate his attention upon such counting. A tambour has therefore been connected to the petcock *S* (see fig. 2) which is moved by the difference in pressure existing in the connection between the mouthpiece and the tension equalizer. With each exhalation a slight pressure is exerted upon the tambour which records upon a kymograph drum. Subsequently an accurate count of the number of respirations per minute and for the entire experimental period may be made from the tambour record and that of a time marker.

METHOD OF RECORDING THE PULSE-RATE.

The important relationship between total metabolism and the pulse-rate, which has been so frequently observed in this Laboratory, made it desirable to secure records of the pulse-rate of the subject during the walking periods. The difficulties experienced in securing counts of the pulse-rate in the earlier research with the bicycle rider have been freely commented upon in the publication giving the report of that study, and it was hoped that some graphic method could be found which would give accurate records of the pulse-rate of a walking man. Unfortunately such a method was not available at the beginning of our research, and counts were therefore made at the wrist or with a stethoscope. Even with a stethoscope at some distance, as employed by Krogh,[1] the noise of the treadmill was such as to make the counting of the pulse-rate extremely difficult. Various forms of tambours[2] were also experimented with in an attempt to register the pulse graphically, but without result. Finally, by using body leads and the Bock-Thoma oscillograph or the Einthoven string galvanometer, we were able to secure graphic records of the pulse-rate of the subject while he was walking upon the treadmill.

Great difficulty was experienced in such photographic registration with the delicate oscillograph and string galvanometer, for not only were there leakages of the 220-volt current used for the motor, but also a static charge on the rapidly revolving belt. Various devices were used for obviating these difficulties, such as having the subject wear rubber-soled shoes and even rubbers over the shoes, but with little success. Finally a metallic brush was made of a piece of brass tubing, 69 cm. long, to which pieces of brass chain, 7 to 9 cm. long, were attached at intervals of approximately 1.5 cm. This brush was so attached to the treadmill that the ends of the chains lay upon the

---

[1]Krogh, Skand. Archiv f. Physiol., 1913, **30**, p. 375.

[2]Bowen, Contributions to Medical Research dedicated to Victor Clarence Vaughan, June 1903, p. 462, Ann Arbor, Mich.

surface of the leather belt. As one end of the chain brush was grounded to the brass tube, when the ends of the chain dragged over the surface of the revolving belt the stray electric currents were picked up and grounded. Satisfactory records could thus be obtained. Unfortunately the conditions of the experimental work in the Laboratory at that time prevented our freeing a galvanometer and oscillograph for the particular purpose of determining the pulse-rate; consequently records could not be regularly secured. Indeed, the few observations obtained were of so striking a character that we can not adequately discuss them in this monograph.[1]

STEP COUNTER.

With a steady electric current, the rate of revolution of the treadmill per minute is presumably fairly constant and the length of the steps in ordinary walking is also doubtless approximately the same; nevertheless it is important to show in these tests the exact number of steps taken, so as to indicate the distance per step and thus furnish an added factor for analyzing the mechanics and physiology of walking. To count the steps automatically was imperative, as even with several assistants an accurate record of the steps during exceedingly rapid

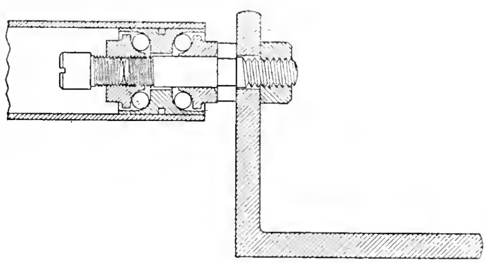

Fig. 4.

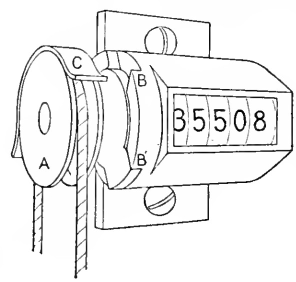

Fig. 5.

Fig. 4.—Detail of ball bearing for steel tubes on the treadmill.
Fig. 5.—Step counter. A pulley *A* is attached to the extended shaft of a revolution counter; a small cord passes over this pulley and is protected by a guard *C*. The shaft automatically stops at *B* and *B'*.

walking would be very difficult to obtain. A small device was therefore employed which counted automatically each vertical motion of the body produced in walking.

To a belt about the waist of the subject was attached a cord leading over two pulleys on the ceiling to a small spring which maintained a tension on the cord. The general arrangement of this device is shown in figure 1 and the details in figures 5 and 6. At each step the subject lifted the body a certain distance and lowered it again. Advantage was taken of this lifting and lowering of the body to raise and lower a small weight (*E*, fig. 6) at the end of a cord which rested upon a pulley (*A*, fig. 5, and *D*, fig. 6) on the shaft of a revolution counter (see fig. 5).

[1]See pp. 85 and 92.

Automatic stops, *B* and *B'*, controlled the distance traveled by the pulley. At each upward movement of the body the cord was lowered and the counter pulled in one direction to the stop, the cord simply slipping over the pulley if the movement continued. As the body returned to its ordinary position, the weight drew the counter back to the second stop. In this way each upward movement of the body was accurately recorded.

Records obtained with this counter of the number of steps taken by one of our subjects in several walking experiments are given in table 2. These are compared with the number of steps counted for the same periods from kymograph records obtained by a method subsequently described.[1] A large number of controls, which were made by counting the movements of the body from the kymograph records and by observations of the counter, showed that this step-counter could be relied upon.

TABLE 2.—*Comparison of steps recorded by step-counter with those counted from kymograph records.*

Date.	Period No.	Distance (meters) per minute.	Steps per minute (counter).	Total number of steps.		
				Counter record.	Counted from kymograph record by	
					Observer I.	Observer II.
1914						
Apr. 24....	2	76.4	116.2	1,687	1,700	1,704
	3	78.4	117.1	1,452	1,454	1,444
Apr. 27....	2	73.5	114.8	1,596	1,588	1,596
	3	78.1	116.0	1,442	1,418	1,400
May 4....	1	114.5	138.3	1,470	1,472	1,472
	2	109.1	133.9	1,491	1,508	1,516
	3	102.0	127.8	1,459	1,476	1,458
May 5....	2	106.0	133.1	1,338	1,340	1,356
	3	102.6	126.5	1,402	1,428	1,420
	4	103.6	126.3	1,269	1,274	1,262

METHOD OF MEASURING HEIGHT TO WHICH THE BODY IS RAISED.

One factor of the mechanics of walking has hitherto been neglected for the most part by writers, particularly when studies of the gaseous metabolism have been made, that is, the height that the body is raised during the process of walking. At each step the body is raised and lowered a distance of approximately 25 to 50 mm., and even higher in running.[2] In any careful research on the physiology of walking in which the efficiency of the body for moving a certain weight a certain distance forward is studied, it is necessary to note the height of this upward movement. For this purpose Dr. Carl Tigerstedt used a device

[1]See p. 40. [2]See table 20, p. 98.

which, in principle, was much like that used by him in studying muscular work done with the foot.[1]

This apparatus, shown in figure 6, consists of a small pointer *A*, traveling on a brass block between two upright guides. The cord *G*, attached to the pointer, passes over a pulley to the belt of the subject, as shown in figure 1. The spiral spring *F*, previously referred to in the description of the step-counter, keeps a tension upon the cord. Obviously as the body is raised the tension of the spiral spring draws the pointer down and as the body is lowered the cord draws the pointer up. Each upward and downward movement of the body may be recorded on a rotating kymograph drum, thus giving a graphic record of the character of each step. A typical record is given in figure 7.

It can be seen that the height to which the body is lifted may be obtained from the kymograph record by measuring each downward stroke of the pointer and adding the sum of the values. Experimental conditions prevented us from using a kymograph with a rapidly rotating drum or a long paper kymograph, and the consequent superimposing of the records shown in figure 7 obviously makes the counting of the number of steps somewhat difficult; nevertheless it is possible and has been done in a number of instances (see table 2). By measuring several points in the curve, an approximate average height of step may easily be obtained; these averages may then be multiplied by the total number of steps recorded on the step-counter and the distance to which the body is raised computed.

In an attempt to sum up these upward movements by means of some automatic arrangement, a special form of work adder-wheel was devised for the purpose. This work adder-wheel, which is shown as *B* in figure 6, relied upon the friction

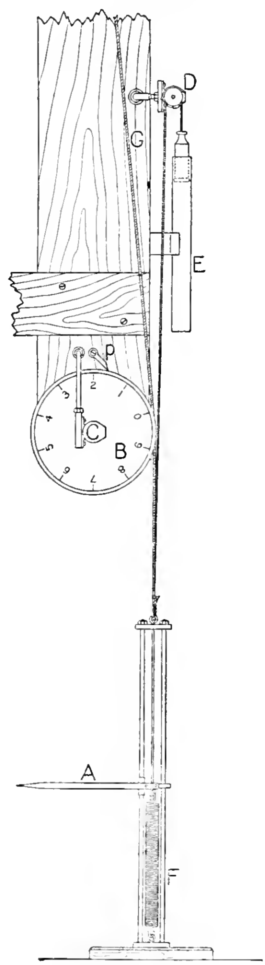

Fig. 6.—Apparatus for recording the height to which the body is lifted, and step-counter with connections.

The cord *G*, connected with the body of the subject, passes over a grooved wheel *B* attached to the shaft of a revolution-counter *C*, a pawl *p*, preventing backward motion. It then passes to a pointer *A* (the marker of Dr. Carl Tigerstedt), tension being supplied by the light spring *F*. An upright cord travels over a grooved pulley on the step-counter *D*, with the tension produced by the small weight traveling in a tube *E*. The height to which the body is raised at each step is thus recorded in a dual manner, first, by the excursions of the pointer *A* over a kymograph drum and second by the accumulated movement of the wheel *B*.

[1] C. Tigerstedt, Skand. Archiv f. Physiol., 1913, **30**, p. 299.

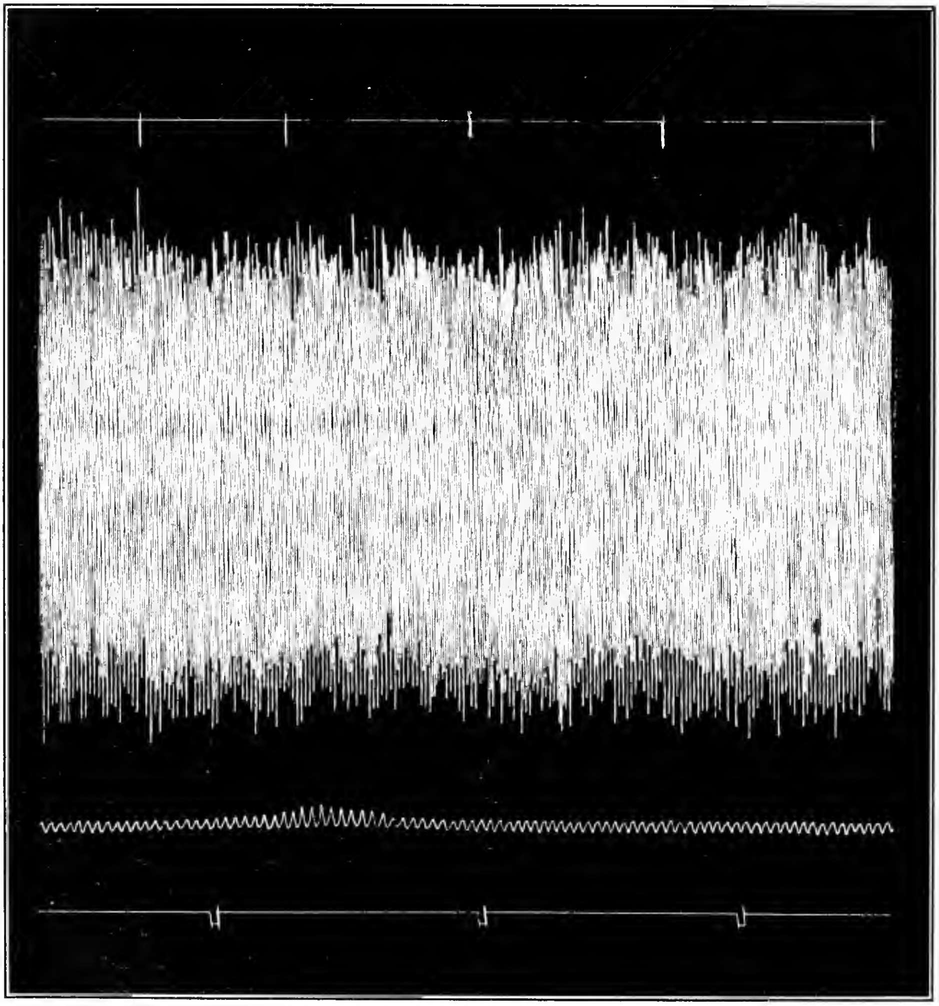

FIG. 7.—Typical kymograph record showing character of step.

The upper line shows the admission of oxygen to the apparatus, each section representing 1 liter; the second line the steps taken by the subject; the third line the respiration; and the lowest line the time in minutes.

of a cord passing over a groove in the wheel to rotate it in one direction as the body was lifted, a pawl *p* preventing any backward motion. When the body returned to the normal position, the cord slipped over the pulley without producing any movement of the wheel. Each upward movement of the body accordingly resulted in a forward motion of the wheel. The work adder-wheel was directly connected to the shaft of a revolution-counter, and a record of the total movement of the wheel was thus obtained. (See *C*, fig. 6.) The total distance the body was raised would theoretically be that found by multiplying the number of revolutions of the wheel by its circumference.

At the very rapid rate of walking used in some of these experiments, great difficulty was experienced in the earlier development of the apparatus in securing an accurate record. The cord would frequently slip and there was considerable reverse movement, for it was not easy to find a pawl arrangement which would work perfectly. This reverse movement or "back-lash" was not overcome until practically the end of the series of observations; recently, however, a very thin laminated spring has been used as a pawl, which has practically eliminated this lost motion. The apparatus as described represents the completed form. As a matter of fact, in many of our experiments we were unable to use the records obtained from this wheel. The height to which the body was raised was therefore determined by the method previously referred to, *i. e.*, measuring on the kymograph curve the general average distance to which the body was raised and multiplying this by the record of the number of steps on the step-counter.

In order to have these measurements of absolute value, the distance traveled by the pointer on the kymograph or that traveled by the cord passing over the work adder-wheel must represent exactly the distance over which the body is elevated or lowered. This assumes that there is no disturbance in the attachment of the cord to the body and that the tension of the spring is such as to prevent any drag or inequality in the movement of the pointer over the drum. As may be seen from the kymograph curve reproduced in figure 7, the constancy in the movement of the pointer was very satisfactory. On the other hand, the method of attaching the cord to the subject was certainly open to serious criticism. Wire was used for the most part, violin string being substituted for such portions as passed over the flexible parts, thus minimizing the tension and the danger of alterations in the length. There was, however, opportunity for considerable flexibility in the play of this cord at the point where it was attached to the belt holding up the trousers of the subject; accordingly, the records obtained with the kymograph and with the work adder-wheel are without doubt invariably somewhat too small and the body was in all instances raised to a higher point than that indicated in table 2. The expediency of attaching a wire direct to the body by means of surgeon's plaster was not resorted to, although the omission was undoubtedly an error in our observations.

PLAN OF RESEARCH.

While this investigation was undertaken primarily with the object of studying the metabolism of walking on a level, certain preliminary observations were necessary, particularly for the purpose of establishing a base-line for comparison with the metabolism during walking. As has previously been stated, certain investigators, in studying the metabolism during walking, have been inclined to employ as a basis of comparison the metabolism determined with the subject in the lying position and without food in the stomach, *i. e.*, maintenance metabolism. Many attempts have also been made to study the metabolism with the subject in the standing or the sitting position, these values being deducted from the total metabolism obtained with the subject walking, the increment being considered as due to the work of forward progression. It was therefore necessary in our research to study the metabolism not only during walking but also under other conditions, thus increasing the number of problems to be studied.

A considerable number of experiments were carried out with the subject standing in different positions, those used being (1) with the subject standing with the body relaxed, as one would stand quietly without external support; (2) leaning against a support at the back; (3) leaning upon a staff; and (4) standing with muscles tense in the position of "attention." By determining the metabolism in these various resting or standing attitudes, all conceivable base-lines could be obtained. Furthermore, it was found that during experiments with rapid walking there was considerable lateral motion of the arms, as is the habit with many walkers, particularly professional pedestrians. Consequently certain experiments were made with the subject standing and swinging the arms from side to side as in a fast walk, but without moving the feet. A number of observations were also made of the metabolism with the subject sitting, with the idea that the values thus obtained might be used for the basal metabolism. As a matter of fact, only a few of the sitting experiments were made with the subject in the post-absorptive condition and the values secured have not been used for actual comparison purposes.

The main object of the research was, of course, the study of the metabolism during walking and specifically the study of the increase in the metabolism due to walking at increasing speeds. In the series of walking experiments, therefore, the subject was required to walk at a very slow speed, then at a medium speed, and finally at a very fast speed. In a few experiments the subject actually ran, thus giving data for comparing the work of forward progression while the subject was walking with that while he was running, two entirely distinct methods of forward progression. Certain observations were also made regarding the effect upon the metabolism of fatigue due to long-continued walking, the subject being required on several days to walk for a considerable length of time.

While, in common with several other investigators, we have believed that the most sharply defined results can be obtained in experiments without food, nevertheless the experimental conditions were such as to make it relatively simple for us to obtain values after the ingestion of food. With this end in view, we made specific studies of the metabolism under the various conditions of standing, walking at various speeds, running, and after fatigue, not only when the subject was without food in the stomach but also after food had been taken. The experiments carried out after food duplicated the experiments with the subject in the post-absorptive condition; it was therefore possible to note whether or not there was a summation effect on the metabolism due to the ingestion of food and to the work.

While in some of the experiments the diet was uncontrolled, in a number of them it was prescribed. The constituents of the meal varied widely in these latter experiments, a special protein diet being supplied on some days, on others a diet containing an excess of fat, and again a diet with a large proportion of carbohydrate. The results of these experiments accordingly gave data as to the effect of a special diet upon the metabolism during walking.

This, in brief, was our plan of research at the beginning of the series of observations. Incidentally a number of other important physiological details were developed as the research progressed. These will be taken up specifically in the discussion of the results of the experiments.

GENERAL ROUTINE OF THE EXPERIMENTS.

It will be seen from the foregoing that the experiments in this research fall naturally into four classes: standing experiments, sitting experiments, walking and running experiments, and experiments with food. From the earlier experience of Cathcart with a subject riding a bicycle, it seemed inadvisable to attempt the establishment of a standard resting base-line to be deducted from the total metabolism of the subject while walking. It was therefore decided that each morning, prior to the walking experiment, measurements should be made of the standing resting metabolism; consequently the research included a large number of standing experiments.

STANDING EXPERIMENTS.

The respiration apparatus used for this research and previously described was designed more especially for measuring the large amounts of carbon dioxide exhaled during severe muscular exercise, and was, in consequence, fitted with two soda-lime bottles, each of which must be weighed. If only the resting metabolism had been determined, a slightly different arrangement would have been preferred, with the use of but one soda-lime bottle, a spirometer form of apparatus being substituted for the rubber bathing-cap and tension-equalizer. Nevertheless, since the resting metabolism with the subject standing was to be used primarily as a base-line to be deducted from the greatly increased metabolism during walking, it was considered that this method of measuring the metabolism during standing would be sufficiently satisfactory for the purpose, and hence the standing metabolism was determined on exactly the same apparatus as that used in the walking experiments. As a matter of fact, the experiments made by Cathcart, and more especially those of Carpenter,[1] have shown that the tension-equalizer form of the unit apparatus gives as accurate measurements of the metabolism during rest as does the spirometer type. In this particular apparatus, however, we could readily have dispensed with the second soda-lime bottle.

After arriving at the Laboratory, the subject arranged his clothing for an ordinary walking experiment and assumed the standing position on the treadmill, this position being maintained for some time prior to the actual experimentation. After the effect of the slight exertion of coming to the Laboratory and of ascending the stairs had passed away, the mouthpiece was inserted, the noseclip attached, and at the proper time, *i. e.*, at the end of a normal expiration, the 3-way valve connecting the subject with the ventilating system of the respiration apparatus was turned. The experiment was then continued in the usual manner

[1]Carpenter, Carnegie Inst. Wash. Pub. 216, 1915, pp. 111 to 118.

for approximately 15 minutes. At the end of a normal expiration the valve was again turned and the experiment was completed. During the entire experiment oxygen was admitted regularly from a cylinder, the gas being passed through a carefully calibrated Bohr gas-meter immersed in water. At the conclusion of the experiment the ventilation was continued for a few minutes to insure the thorough sweeping out of all the carbon dioxide; finally the tension-equalizer was filled with oxygen to the same tension that existed at the beginning of the experiment.

Owing to the greatly increased carbon-dioxide production during severe muscular work, the ventilating current was so adjusted that the ventilating pump would cause 80 to 90 liters of air to pass by the mouth of the subject per minute, thus minimizing the danger of the rebreathing of the air. Furthermore, by means of the supplementary valve *M* (see fig. 2, page 34), the dead space in the rubber tube leading from the mouthpiece to the main air-pipe was wholly eliminated, for when the valve *N* had been turned after the beginning of the experiment, all of the air passed immediately by the mouthpiece. While this deflection of the air-current was unnecessary in the experiments with the subject standing, nevertheless it was also used in these experiments in order that the procedure might be the same in both series.

Since it is important to note whether or not the subject remained in essentially the same degree of muscular repose throughout the standing experiments, a graphic record was obtained of the degree of movement by connecting the subject with a cord attached to a movable pointer traveling over a smoked-paper kymograph. In an ideal experiment the course of the pointer would be a straight line. While it was impossible for the subject to remain as perfectly quiet as he would when lying upon a comfortable couch, nevertheless the regularity and constancy of the muscular repose of the subject from experiment to experiment was, to say the least, very striking. We are therefore safe in assuming that in practically no experiment were the irregularities in the metabolism for the standing position attributable to changes in the degree of muscular repose of the individual, except in those tests in which special positions while standing were assumed, such as the position of "attention."

SITTING EXPERIMENTS.

A few sitting experiments were also made with one of the subjects. These were not used as a base-line, but are recorded simply to show that an endeavor was made to secure the best possible base-line for deduction from the total metabolism obtained during walking. The increment in the metabolism for the sitting position was unfortunately not studied with sufficient sharpness to make a definite conclusion possible.

WALKING AND RUNNING EXPERIMENTS.

In the walking and running experiments the routine was essentially that previously outlined for the standing experiments, save that during the entire period and for several minutes before the experiment began the subject was walking upon an electrically driven treadmill which was kept in motion at a definite rate of speed. These rates of speed varied from 53 meters per minute to 149 meters per minute. The flexibility of the mouthpiece and its attendant by-pass made it possible for the subject to walk with perfect comfort at these varying speeds and the vertical movement of the body with each step did not interfere in the slightest with the correct measurement of the gaseous exchange. With a slow speed, there was no noticeable extraneous muscular effort other than that of walking; with a high speed the subject made vigorous lateral motions of the arms, as is quite common with professional pedestrians when walking at high speed. As previously noted, an attempt was made to measure the influence of this lateral motion by studying the metabolism with the subject standing and swinging the arms. In a number of the experiments the subject ran, although the rate of progression was but little higher than in the experiments with fast walking.

EXPERIMENTS WITH FOOD.

A considerable number of experiments were made after a breakfast selected by the subject; a few were also made after dinner, the diet being uncontrolled. In the experiments in which a study was made of the possible influence of diets containing a preponderance of protein, fat, or carbohydrate, the first meal of the day was given to the subject at the Laboratory after a walking experiment in the forenoon in which he was in the post-absorptive state. This meal consisted of steak, rice, potatoes, or various fats. A second walking experiment was then made under otherwise identical conditions. The exact weight of food was not recorded, since our only aim was to make sure that the body was plentifully supplied with the special food constituent being studied. In general, the subject ate all that he possibly could and as a consequence was frequently disinclined to walk in the afternoon.

A careful study of the effect of muscular work upon the urine was impracticable, hence no analyses of the urine accompany these observations. Previous tests with one of the subjects have shown, however, that the accomplishment of a large amount of severe muscular work was not accompanied by an excessive excretion of nitrogenous products in the urine.[1]

---

[1]Benedict and Cathcart, Carnegie Inst. Wash. Pub. 187, 1913, p. 98.

SUBJECTS.

In this series of observations two subjects were used, both of whom were more or less trained to severe muscular activity, as one (A. J. O.) was a semi-professional baseball player and the other (M. A. M.) a professional bicyclist. The preliminary observations in this research were carried out by Dr. Carl Tigerstedt with the subject A. J. O. (subject I), a man of athletic build, who readily adapted himself to the observations on the treadmill and with the respiration apparatus. He was 29 years of age, 180 cm. in height, and had a body-weight with clothing varying from 72.1 kilograms to 74.8 kilograms and without clothing of 69.7 kilograms. Since in this study one of the prime objects was to note the energy required to move 1 kilogram of material in the forward direction 1 meter, *i. e.*, 1 horizontal kilogrammeter, the body-weight with clothing is of importance in each experiment. These weights are given in detail in table 13 (page 78).

The major portion of the research was devoted to a study of forward progression at varying speeds with the subject M. A. M., who had previously served as the subject of Cathcart in the study of the muscular work of bicycle-riding. This subject, who in this publication is designated as subject II,[1] was 31 years of age, 177 cm. in height, and had a body-weight with clothing varying from 69.9 to 72.4 kilograms. The average body-weight without clothing during this series of experiments was 68.3 kilograms. The body-weight with clothing is given for each experiment in tables 14 and 16 (pages 83 and 88).

[1]Further data regarding the body measurements, etc., of this subject may be found in the report of the previous study on muscular work. See Benedict and Cathcart, Carnegie Inst. Wash. Pub. 187, 1913, p. 35.

STATISTICS OF EXPERIMENTS.

The data regarding the experimental conditions, the respiratory exchange, and the mechanics of walking for the experiments with subject I (A. J. O.) are given in table 3; the data for subject II (M. A. M.) appear in table 4.

Table 3.—*Summary of results obtained with subject I in experiments without food, during the period from Nov. 26, 1913, to Dec. 27, 1913.*

[Observations made by Dr. Carl Tigerstedt. Values per minute.]

Date and condition.	Duration.		Carbon dioxide.	Oxygen.	Respiratory quotient.	Average pulse-rate.	Average respiration-rate.	Distance.	Raising of body.
Nov. 26.[1]	*min.*	*sec.*	*c.c.*	*c.c.*				*meters.*	*meters.*
Standing,[2] $10^{h}\ 10^{m}$ a. m.	15	17	283	343	0.82	..	....	....	....
Standing,[2] $10^{h}\ 45^{m}$ a. m.	15	45	278	321	.86	..	18.3	....	....
Food about 1 p. m.									
Standing, $2^{h}\ 25^{m}$ p. m.	15	04	277	341	.81	80	18.0	....	....
Standing, $2^{h}\ 45^{m}$ p. m.	15	35	268	328	.82	87	18.4	....	....
Walking,[3] $3^{h}\ 24^{m}$ p. m.	15	15	943	1015	.93	..	27.9	75.3	3.57
Nov. 28.									
Standing, $10^{h}\ 29^{m}$ a. m.	15	07	226	284	.80	85	16.3	....	....
Standing, $11^{h}\ 03^{m}$ a. m.	15	06	222	291	.76	96	17.2	....	....
Standing, $11^{h}\ 30^{m}$ a. m.	15	48	218	279	.78	95	17.7	....	....
Nov. 29.									
Standing, $9^{h}\ 16^{m}$ a. m.	15	18	228	282	.81	91	18.6	....	....
Standing, $9^{h}\ 50^{m}$ a. m.	15	19	219	282	.78	94	18.3	....	....
Walking,[3] $10^{h}\ 22^{m}$ a. m.	15	02	886	873	1.02	..	25.7	75.1	3.15
Dec 1.									
Standing, $9^{h}\ 30^{m}$ a. m.	15	11	222	276	.81	90	19.0	....	....
Standing, $9^{h}\ 57^{m}$ a. m.	15	12	217	282	.77	94	19.5	....	....
Walking,[3] $10^{h}\ 51^{m}$ a. m.	9	59	692	852	.81	..	25.4	76.0	3.26
Walking,[3] $11^{h}\ 34^{m}$ a. m.	9	57	731	904	.81	..	24.5	76.6	3.36
Dec. 2.									
Standing, $8^{h}\ 54^{m}$ a. m.	15	28	234	290	.81	88	19.4	....	....
Standing, $9^{h}\ 17^{m}$ a. m.	15	22	223	289	.77	90	21.1	....	....
Standing, $10^{h}\ 15^{m}$ a. m.	15	25	214	280	.77	88	21.5	....	....
Walking,[3] $10^{h}\ 30^{m}$ a. m.	4	44	630	853	.74	..	26.8	76.2	3.20
Walking,[3] $11^{h}\ 18^{m}$ a. m.	10	16	695	849	.82	..	25.3	76.8	4.62
Dec. 3.									
Standing, $9^{h}\ 10^{m}$ a. m.	15	07	226	286	.79	90	19.5	....	....
Standing, $9^{h}\ 38^{m}$ a. m.	15	07	214	269	.80	99	21.8	....	....
Standing, $10^{h}\ 06^{m}$ a. m.	15	05	209	270	.78	97	21.9	....	....
Walking,[3] $10^{h}\ 45^{m}$ a. m.	10	47	685	845	.81	..	27.3	76.5	3.57
Walking,[3] $11^{h}\ 05^{m}$ a. m.	10	17	701	842	.83	..	26.7	77.2	3.62
Walking,[3] $11^{h}\ 35^{m}$ a. m.	10	17	697	872	.80	..	25.5	77.5	3.68
Standing, $11^{h}\ 56^{m}$ a. m.	13	55	215	270	.80	85	23.0	....	....
Standing, $12^{h}\ 20^{m}$ p. m.	15	09	206	267	.77	89	23.0	....	....

[1]The subject had breakfast at about 7 a. m.

[2]Throughout this summary of results, the designation "standing" signifies standing in a relaxed position unless otherwise specified.

[3]Subject I walked at a rate of not far from 105 steps per minute throughout the walking series, except on December 22, 23, and 27. The total distance during the period on Nov. 26 was 1,148 meters; on Nov. 29, 1,129 meters; during the periods on Dec. 1, 1,520 meters; Dec. 2, 1,149 meters; Dec. 3, 2,415 meters. The subject did not walk between periods.

TABLE 3.—*Summary of results obtained with subject I in experiments without food, during the period from Nov. 26, 1913, to Dec. 27, 1913*—Continued.

[Observations made by Dr. Carl Tigerstedt. Values per minute.]

Date and condition.	Duration.		Carbon dioxide.	Oxygen.	Respiratory quotient.	Average pulse-rate.	Average respiration-rate.	Distance.	Raising of body.
Dec. 4.	*min.*	*sec.*	*c.c.*	*c.c.*				*meters.*	*meters.*
Standing, 9^{h} 12^{m} a. m. . . .	15	02	220	267	0.82	86	22.5	....	....
Standing, 9^{h} 21^{m} a. m. . . .	15	10	208	269	.77	97	22.8	....	....
Standing, 10^{h} 04^{m} a. m. . .	15	10	213	265	.80	88	22.4	....	....
Walking,[1] 10^{h} 35^{m} a. m. . .	10	19	690	874	.79	..	24.9	77.7	3.41
Walking,[1] 11^{h} 30^{m} a. m. . .	10	04	695	882	.79	..	26.4	77.7	3.68
Walking,[1] 12^{h} 03^{m} p. m. . .	10	06	703	857	.82	..	25.2	78.2	3.57
Dec. 5.									
Standing, 9^{h} 18^{m} a. m. . . .	16	03	239	335	.71	100	21.8	....	....
Standing, 9^{h} 48^{m} a. m. . . .	15	08	240	340	.71	110	23.6	....	....
Standing, 10^{h} 18^{m} a. m. . .	15	07	230	328	.70	105	24.3	....	....
Walking,[1] 10^{h} 52^{m} a. m. . .	10	03	720	928	.78	..	26.9	75.7	3.57
Walking,[1] 11^{h} 12^{m} a. m. . .	10	06	790	925	.85	..	27.5	78.2	4.10
Walking,[1] 11^{h} 37^{m} a. m. . .	10	05	761	983	.77	..	29.9	79.0	4.10
Dec. 8.									
Standing, 9^{h} 17^{m} a. m. . . .	15	01	205	272	.75	89	20.3	....	....
Standing, 9^{h} 42^{m} a. m. . . .	15	06	209	270	.77	91	20.9	....	....
Standing, 10^{h} 11^{m} a. m. . .	15	09	205	271	.76	93	22.4	....	....
Walking,[2] 10^{h} 46^{m} a. m. . .	11	57	692	829	.84	..	24.7	76.5	3.52
Walking,[2] 11^{h} 15^{m} a. m. . .	11	59	729	889	.82	..	24.8	78.6	3.78
Walking,[2] 11^{h} 41^{m} a. m. . .	12	04	721	887	.81	..	23.9	79.3	4.04
Walking,[2] 12^{h} 07^{m} p. m. . .	11	54	722	920	.78	..	27.2	79.7	4.15
Dec. 9.[3]									
Standing, 9 a. m.	15	06	255	357	.71	120	22.6	....	....
Standing, 9^{h} 39^{m} a. m. . . .	15	10	248	345	.72	110	22.8	....	....
Standing, 10^{h} 25^{m} a. m. . .	15	35	242	320	.76	105	23.2	....	....
Walking,[2] 11^{h} 07^{m} a. m. . .	13	54	792	952	.83	..	23.6	76.0	3.68
Walking,[2] 11^{h} 33^{m} a. m. . .	14	00	782	899	.87	..	26.9	78.3	3.89
Walking,[2] 12^{h} 11^{m} p. m. . .	14	03	753	891	.85	..	27.0	79.1	4.04
Dec. 15.									
Standing, 9^{h} 06^{m} a. m. . . .	15	08	233	279	.83	89	21.6	....	....
Standing, 9^{h} 37^{m} a. m. . . .	15	17	212	268	.79	91	22.3	....	....
Standing, 10^{h} 04^{m} a. m. . .	15	12	220	278	.79	88	22.8	....	....
Walking,[2] 10^{h} 32^{m} a. m. . .	15	02	808	980	.82	..	23.0	74.2	3.68
Walking,[2] 10^{h} 58^{m} a. m. . .	15	05	757	891	.85	..	26.4	75.6	3.83
Walking,[2] 11^{h} 25^{m} a. m. . .	15	02	734	875	.84	..	26.2	76.3	3.94
Walking,[2] 11^{h} 50^{m} a. m. . .	17	18	727	...	....	..	28.3	76.3	3.99
Dec. 16.									
Standing, 9^{h} 17^{m} a. m. . . .	20	07	220	290	.76	103	21.8	....	....
Standing, 9^{h} 48^{m} a. m. . . .	20	12	221	284	.78	100	22.3	....	....
Standing, 10^{h} 17^{m} a. m. . .	20	10	229	283	.81	99	22.4	....	....
Walking,[2] 11^{h} 05^{m} a. m. . .	20	06	758	882	.86	..	23.5	75.1	3.89
Walking,[2] 11^{h} 37^{m} a. m. . .	20	00	754	853	.88	..	26.2	76.7	3.99
Walking,[2] 12^{h} 19^{m} p. m. . .	20	08	721	793	.91	..	28.1	77.6	4.20

[1]Subject I walked at a rate of not far from 105 steps per minute throughout the walking series, except on December 22, 23, and 27. The total distance walked during the periods on Dec. 4 was 2,374 meters; Dec. 5, 4,303 meters. The subject did not walk between periods.

[2]The total distance walked on Dec. 8 was 7,363 meters; on Dec. 9, 6,114 meters; Dec. 15, 7,219 meters; Dec. 16, 7,247 meters. The subject walked between periods.

[3]Previous to the experiment of Dec. 9 the subject took an egg-phosphate.

TABLE 3.—*Summary of results obtained with subject I in experiments without food, during the period from Nov. 26, 1913, to Dec. 27, 1913*—Concluded.

[Observations made by Dr. Carl Tigerstedt. Values per minute.]

Date and condition.	Duration.		Carbon dioxide.	Oxygen.	Respiratory quotient.	Average pulse-rate.	Average respiration-rate.	Distance.	Raising of body.
	min.	*sec.*	*c.c.*	*c.c.*				*meters.*	*meters.*
Dec. 17.									
Standing, 8h 57m a. m.	25	00	230	277	0.83	89	20.5	....	....
Standing, 9h 32m a. m.	25	07	221	270	.82	92	21.4	....	....
Standing, 10h 07m a. m.	25	07	217	266	.82	93	22.1	....	....
Walking,[1] 10h 44m a. m.	20	09	695	823	.84	..	25.3	75.0	3.73
Walking,[1] 11h 14m a. m.	20	07	708	851	.83	..	24.9	76.4	3.89
Walking,[1] 11h 45m a. m.	20	16	706	872	.81	..	26.5	78.1	4.15
Walking,[1] 12h 18m p. m.	20	08	719	905	.79	..	26.5	78.6	4.15
Dec. 18.									
Standing, 9h 03m a. m.	25	05	238	272	.88	88	21.1	....	....
Standing, 9h 54m a. m.	25	33	230	263	.87	88	21.3	....	....
Standing, 10h 34m a. m.	25	13	220	255	.86	83	21.6	....	....
Walking,[1] 11h 08m a. m.	20	04	726	811	.89	..	23.9	75.3	3.52
Walking,[1] 11h 40m a. m.	20	28	740	833	.89	..	25.2	76.4	3.68
Walking,[1] 12h 10m p. m.	20	04	730	864	.84	..	27.7	76.7	3.68
Walking,[1] 12h 39m p. m.	20	12	734	867	.85	..	27.3	76.9	3.73
Dec. 19.									
Standing, 9h 43m a. m.	25	03	238	279	.85	96	22.5	....	....
Standing, 10h 16m a. m.	25	06	239	282	.85	97	23.3	....	....
Standing, 10h 49m a. m.	25	06	241	275	.88	100	23.1	....	....
Walking,[1] 11h 25m a. m.	20	06	789	869	.91	..	23.9	76.1	3.83
Walking,[1] 11h 54m a. m.	20	06	772	860	.90	..	28.1	77.9	3.99
Walking,[1] 12h 21m p. m.	20	10	755	871	.87	..	29.0	78.3	4.10
Walking,[1] 12h 52m p. m.	10	40	759	872	.87	..	29.8	78.7	4.20
Dec. 20.									
Standing, 8h 55m a. m.	25	06	237	272	.87	99	23.3	....	....
Standing, 9h 29m a. m.	25	17	...	271	....	106	22.5	....	....
Standing, 10h 06m a. m.	25	10	224	273	.82	106	23.2	....	....
Standing, 11h 10m a. m.	24	56	216	263	.82	100	22.5	....	....
Walking,[1] 11h 44m a. m.	20	04	690	825	.84	..	26.1	76.2	3.68
Walking,[1] 12h 11m p. m.	20	07	735	884	.83	..	28.5	77.7	4.04
Walking,[1] 12h 40m p. m.	20	02	731	924	.79	..	30.1	78.6	4.20
Walking,[1] 1h 02m p. m.	19	59	747	934	.80	..	31.3	78.9	4.25
Dec. 22.									
Walking,[1] 10h 17m a. m.	20	15	718	873	.82	..	27.4	76.3	4.07
Walking,[1] 10h 47m a. m.	20	06	610	790	.77	..	28.6	65.9	3.17
Walking,[1] 11h 20m a. m.	20	07	641	901	.71	..	30.2	77.4	4.28
Walking,[1] 11h 48m a. m.	20	06	600	788	.76	..	29.7	67.5	3.41
Dec. 23.									
Walking,[1] 9h 25m a. m.	20	29	695	833	.83	..	25.7	75.9	3.97
Walking,[1] 9h 59m a. m.	20	47	589	740	.80	..	24.2	66.4	3.07
Walking,[1] 10h 38m a. m.	20	18	694	863	.80	..	27.2	76.9	4.08
Walking,[1] 11h 12m a. m.	20	06	602	764	.79	..	26.0	66.4	3.30
Dec. 27.									
Walking,[1] 9h 56m a. m.	21	53	685	846	.81	..	27.0	78.4	4.06
Walking,[1] 10h 41m a. m.	20	43	563	725	.78	..	26.9	65.2	3.02
Walking,[1] 11h 15m a. m.	20	52	664	852	.78	..	28.6	78.6	4.13
Walking,[1] 11h 48m a. m.	20	11	560	732	.76	..	29.1	65.1	3.02

[1]Subject I walked at a rate of not far from 105 steps per minute throughout the walking series except on Dec. 22, 23, and 27. The total distance walked on Dec. 17 was 8,798 meters; Dec. 18, 8,435 meters; Dec. 19, 7,581 meters; Dec. 20, 8,142 meters; Dec. 22, 10,075 meters; Dec. 23, 10,338 meters; Dec. 27, 11,908 meters. The subject walked between periods. The steps per minute in the last three periods on Dec. 22 were 95, 101, and 95; during the periods on Dec. 23, 105, 94, 103, and 96; on Dec. 27, 106, 94, 103, and 92, respectively.

TABLE 4.—*Summary of results in experiments with subject II, during the period from Mar. 16, 1914, to May 15, 1914.*

[Values per minute.]

Date, condition, and time.	Duration.		Carbon dioxide.	Oxygen.	Respiratory quotient.	Average pulse-rate.	Average respiration-rate.	Distance.	Steps.	Raising of body.
Mar. 16.										
Food, 7[h] 40[m] a. m.:	*min.*	*sec.*	*c.c.*	*c.c.*				*meters.*		*meters.*
Sitting,[1] 9[h] 38[m] a. m.	21	26	218	281	0.77	..	18.7	....	...	....
Sitting,[1] 10[h] 26[m] a. m.	23	44	203	256	.79	..	18.3	....	...	....
Standing,[2] 11[h] 22[m] a. m.	20	13	217	274	.79	..	18.7	....	...	....
Standing,[2] 11[h] 56[m] a. m.	20	14	223	286	.78	..	20.2	....	...	....
Walking,[3] 12[h] 53[m] p. m.	19	45	672	810	.83	..	26.4	74.3	107	2.88
Food, 1[h] 45[m] p. m.:										
Sitting, 3[h] 05[m] p. m.	21	28	250	304	.82	..	19.9	....	...	....
Standing, 3[h] 52[m] p. m.	18	29	261	319	.82	..	22.1	....	...	....
Walking,[3] 4[h] 30[m] p. m.	21	27	721	815	.88	..	29.2	75.3	97	3.17
Mar. 17.										
Food, 12 noon:										
Sitting, 3[h] 45[m] p. m.	18	36	213	272	.78	..	18.1	....	...	....
Mar. 18.										
Food, 7[h] 30[m] a. m.:										
Sitting, 9[h] 08[m] a. m.	20	51	233	286	.82	..	19.2	....	...	....
Standing, 10 a. m.	18	25	244	293	.83	..	18.2	....	...	....
Walking,[4] 10[h] 55[m] a. m.	18	39	699	840	.83	..	25.1	76.0	98	3.34
Walking,[4] 11[h] 35[m] a. m.	19	19	702	...	...	..	27.0	78.0	105	3.62
Food, 12[h] 30[m] p. m.:										
Sitting, 3[h] 09[m] p. m.	21	5	248	297	.84	..	19.3	....	...	....
Walking,[4] 3[h] 54[m] p. m.	20	57	758	808	.94	..	26.9	76.3	99	3.75
Mar. 19.										
Food, 7[h] 30[m] a. m.:										
Sitting, 9[h] 24[m] a. m.	18	49	242	282	.86	67	18.7	....	...	....
Standing, 10[h] 37[m] a. m.	17	29	231	295	.78	75	19.3	....	...	....
Walking,[5] 11[h] 21[m] a. m.	20	31	720	870	.83	..	26.9	74.9	99	3.16
Food, 12[h] 30[m] p. m.:										
Sitting, 2[h] 18[m] p. m.	18	21	259	322	.80	77	21.0	....	...	....
Standing, 3[h] 05[m] p. m.	17	5	247	303	.82	86	20.7	....	...	....
Walking,[5] 3[h] 50[m] p. m.	18	11	739	833	.89	..	28.1	74.9	96	3.55
Mar. 20.										
Without food:										
Standing,[6] 9[h] 58[m] a. m.	18	48	218	275	.79	71	16.8	....	...	....
Walking,[7] 10[h] 51[m] a. m.	17	52	583	725	.80	..	20.4	....	92	2.61
Food, 12[h] 30[m] p. m.:										
Standing,[8] 3[h] 56[m] p. m.	16	28	274	318	.86	87	20.3	....	...	....
Walking,[7] 4[h] 34[m] p. m.	19	32	602	634	.95	..	22.6	52.7	92	2.39

[1]During "sitting" periods in this summary the subject sat comfortably in a chair and was as quiet as possible.

[2]The designation "standing" signifies standing in a relaxed position unless otherwise specified. The subject stood as quietly as possible.

[3]Total distance preliminary to and during period before lunch, 1,633 meters; after lunch, 1,740 meters.

[4]Total distance before lunch, 4,573 meters, the walking being continuous; after lunch, distance preliminary to and during period, 1,690 meters.

[5]Total distance preliminary to and during period before lunch, 1,573 meters; after lunch, 1,462 meters.

[6]Standing on one leg, right leg relaxed, with hands in pockets. Subject found this more tiring than standing on both legs.

[7]Total distance preliminary to and during period before lunch, about 1,057 meters; after lunch the distance was 1,055 meters. The subject's hands swung loosely at his side as he walked. It should be stated that this was the case except as otherwise indicated.

[8]Standing on both legs with hands in pockets.

TABLE 4.—*Summary of results in experiments with subject II, during the period from Mar. 16, 1914, to May 15, 1914*—Continued.

[Values per minute.]

Date, condition, and time.	Duration.		Carbon dioxide.	Oxygen.	Respiratory quotient.	Average pulse-rate.	Average respiration-rate.	Distance.	Steps.	Raising of body.
Mar. 21.										
Food, 7^{h} 30^{m} a. m.:	*min.*	*sec.*	*c.c.*	*c.c.*				*meters.*		*meters.*
Standing,[1] 9^{h} 15^{m} a. m	19	27	271	338	0.80	98	20.7	....	...	....
Standing, attention,[2] 10^{h} 09^{m} a. m.	16	58	249	288	.87	91	21.2	....	...	....
Walking,[3] 11^{h} 15^{m} a. m.	22	2	675	764	.88	..	22.3	57.9	104	3.11
Food, 12^{h} 30^{m} p. m.:										
Standing,[1] 2^{h} 09^{m} p. m.	15	44	275	355	.78	96	20.9	....	...	....
Standing, attention,[2] 2^{h} 48^{m} p.m.	15	5	270	295	.92	94	22.6	....	...	....
Walking,[3] 3^{h} 32^{m} p. m.	20	18	593	699	.85	..	23.9	52.8	92	2.59
Mar. 23.										
Food, 7 a. m.:										
Standing, staff,[4] 9^{h} 50^{m} a. m.	16	15	282	333	.84	74	20.5	....	...	....
Walking,[5] 10^{h} 37^{m} a. m.	19	19	625	689	.91	..	22.8	57.9	93	2.74
Walking,[5] 11^{h} 34^{m} a. m.	18	36	670	764	.88	..	25.2	57.5	99	2.61
Mar. 24.										
Without food:										
Standing, staff, 9^{h} 07^{m} a. m.	18	23	217	250	.87	82	18.8	....	...	....
Standing, support,[6] 9^{h} 54^{m} a. m.	19	6	196	256	.77	79	17.7	....	...	....
Walking,[7] 11^{h} 05^{m} a. m.	16	13	628	778	.81	..	21.9	60.6	95	1.09
Food, 12^{h} 15^{m} p. m.:										
Standing, staff, 1^{h} 56^{m} p. m.	16	49	289	356	.81	95	22.1	....	...	....
Standing, support,[6] 2^{h} 40^{m} p. m.	17	51	254	301	.84	92	20.7	....	...	....
Walking,[7] 3^{h} 34^{m} p. m.	16	1	734	809	.91	..	21.3	62.7	101	.81
Mar. 25.										
Without food:										
Sitting, 9^{h} 58^{m} a. m.	18	5	192	260	.74	59	18.0	....	...	....
Standing, attention,[8] 10^{h} 57^{m} a. m.	14	11	206	265	.78	72	18.7	....	...	....
Walking,[9] 11^{h} 52^{m} a. m.	17	3	570	709	.80	..	19.8	60.6	92	1.77
Food, 12^{h} 30^{m} p. m.:										
Sitting, 2^{h} 03^{m} p. m.	15	15	272	316	.86	73	19.6	....	...	....
Standing, attention,[8] 2^{h} 38^{m} p.m.	13	53	292	309	.95	95	20.2	....	...	....
Walking,[9] 3^{h} 39^{m} p. m.	17	33	704	726	.97	..	24.1	61.1	90	1.50

[1]Standing with weight on one leg, the other leg relaxed; hands in pockets.

[2]Standing on both legs, with hands at sides, in tense position; subject stiff and tired after the period was finished.

[3]Total distance before lunch, 1,362 meters; after lunch, 1,113 meters.

[4]Standing relaxed, leaning on long staff, with one hand above the other on the staff.

[5]Total distance, 2,568 meters, the walking being continuous. During the first of the two periods subject's hands were upon a support at either side; in the second period his hands were swinging at his sides.

[6]Leaning against support. In the morning subject stood with hands in his pockets and was not sufficiently comfortable; in the afternoon he placed his hands on his back.

[7]Total distance before lunch, 1,150 meters; after lunch, 1,190 meters. In the first period on this day a counter was first used to obtain the number of steps and a wheel for measuring the total height of the raising of the body. Both these devices were generally in use during the remainder of the series.

[8]Subject could not wholly secure the erect position desired; at the end of the afternoon period he was not able to stand longer.

[9]Total distance before lunch, 1,189 meters; after lunch, 1,295 meters. In both periods, the subject supported his hands on his legs.

TABLE 4.—*Summary of results in experiments with subject II, during the period from Mar. 16, 1914, to May 15, 1914*—Continued.

[Values per minute.]

Date, condition, and time.	Duration.		Carbon dioxide.	Oxygen.	Respiratory quotient.	Average pulse-rate.	Average respiration-rate.	Distance.	Steps.	Raising of body.
Mar. 26.										
Without food:	*min.*	*sec.*	*c.c.*	*c.c.*				*meters.*		*meters.*
Standing, staff, 9^{h} 10^{m} a. m.	17	15	223	253	0.88	80	18.7	....	...	....
Standing, support,[1] 9^{h} 49^{m} a. m.	18	18	201	238	.84	79	19.1	....	...	....
Walking,[2] 10^{h} 58^{m} a. m.	17	49	605	701	.86	..	22.0	62.7	99	3.09
Food, 12^{h} 30^{m} p. m.:										
Standing, staff, 2 p. m.	15	53	274	317	.86	94	20.6	....	...	....
Standing, support, 2^{h} 38^{m} p. m.	16	11	254	289	.88	93	21.8	....	...	....
Walking,[2] 3^{h} 35^{m} p. m.	18	35	694	738	.94	..	25.4	60.7	96	2.30
Mar. 27.										
Without food:										
Sitting, 9^{h} 18^{m} a. m.	12	32	195	234	.83	58	17.6	....	...	....
Standing, attention, 10^{h} 03^{m} a. m.	15	5	219	272	.80	71	18.9	....	...	....
Walking,[3] 11^{h} 56^{m} a. m.	18	8	544	652	.83	..	22.8	57.6	95	2.09
Food, 12^{h} 45^{m} p. m.:										
Standing, attention, 2^{h} 24^{m} p.m.	15	14	294	298	.99	95	22.4	....	...	....
Walking,[3] 2^{h} 57^{m} p. m.	18	25	681	727	.94	..	27.1	58.6	91	2.15
Mar. 28.										
Food, 7^{h} 30^{m} a. m.:										
Standing, support, 9^{h} 40^{m} a. m.	13	43	279	304	.92	87	20.7	....	...	....
Standing, support, 10^{h} 15^{m} a. m.	17	43	246	276	.89	81	21.0	....	...	....
Walking,[4] 11^{h} 30^{m} a. m.	16	16	654	702	.93	..	22.1	59.4	97	2.52
Food, 12^{h} 30^{m} p. m.:										
Standing, support, 1^{h} 44^{m} p. m.	16	48	280	314	.89	85	21.0	....	...	....
Walking,[4] 2^{h} 24^{m} p. m.	17	12	743	759	.98	..	24.5	59.3	96	2.12
Mar. 30.										
Food, 7^{h} 30^{m} a. m.:										
Standing, attention, 9^{h} 36^{m} a. m.	15	54	261	271	.96	76	20.2	....	...	....
Standing, staff, 10^{h} 15^{m} a. m.	14	51	261	296	.88	71	18.9	....	...	....
Walking,[5] 11^{h} 17^{m} a. m.	17	15	658	744	.88	..	19.2	58.5	100	2.26
Food, 12^{h} 45^{m} p. m.:										
Standing, staff, 1^{h} 50^{m} p. m.	15	8	318	339	.94	95	21.3	....	...	....
Walking,[5] 2^{h} 27^{m} p. m.	16	56	681	722	.94	..	24.8	58.5	92	2.40
Walking,[5] 3^{h} 26^{m} p. m.	15	11	666	709	.94	..	21.9	57.3	99	2.24
Mar. 31.										
Without food:										
Standing, support, 8^{h} 38^{m} a. m.	17	48	214	239	.89	77	18.4	....	...	....
Standing, relaxed, 9^{h} 21^{m} a. m.	16	40	209	260	.80	71	17.8	....	...	....
Standing, attention, 10^{h} 02^{m} a. m.	13	9	233	272	.86	75	19.4	....	...	....
Walking,[6] 11^{h} 47^{m} a. m.	15	59	571	673	.85	..	21.6	57.2	98	2.01

[1]Leaning comfortably against support, hands on back.

[2]Total distance before lunch, 1,286 meters; after lunch, 1,345 meters. Subject held his hands on his legs as he walked.

[3]Total distance before lunch, 1,184 meters; after lunch, 1,266 meters. Subject held his hands at his sides as he walked.

[4]Total distance before lunch, 1,158 meters; after lunch, 1,210 meters. In the morning, subject walked with hands held on his legs; in the afternoon his hands were swinging at his sides.

[5]Total distance before lunch, 1,198 meters, subject walking with hands swinging. After lunch distance was 2,229 meters, hands being on support in the first period and swinging at his sides in the second period. Most of the time between periods he was not walking.

[6]Total distance before lunch, 1,085 meters; after lunch, 1,020 meters.

TABLE 4.—*Summary of results in experiments with subject II, during the period from Mar. 16, 1914, to May 15, 1914*—Continued.

[Values per minute.]

Date, condition, and time.	Duration.		Carbon dioxide.	Oxygen.	Respiratory quotient.	Average pulse-rate.	Average respiration-rate.	Distance.	Steps.	Raising of body.
Mar. 31—Continued.										
Food, 1 p. m.:	*min.*	*sec.*	*c.c.*	*c.c.*				*meters.*		*meters.*
Walking,[1] 2^h 08^m p. m.	14	57	685	705	0.97	..	23.9	57.7	99	1.72
Standing, relaxed, 2^h 55^m p. m.	15	36	277	345	.80	89	20.6	....	...	....
Standing, attention, 3^h 40^m p. m.	11	52	265	326	.81	89	20.7	....	...	....
Apr. 1.										
Without food:										
Standing, 9^h 50^m a. m.	15	13	213	266	.80	75	17.9	....	...	....
Walking,[2] 11^h 21^m a. m.	15	57	563	699	.81	..	21.5	59.3	100	2.22
Food, 12 noon:										
Standing, 1^h 42^m p. m.	16	30	283	319	.89	86	20.2	....	...	....
Apr. 2.										
Food, 7^h 15^m a. m.:										
Standing, support, 8^h 44^m a. m.	15	30	273	306	.89	89	20.0	....	...	....
Standing, relaxed, 9^h 53^m a. m.	12	15	253	281	.90	86	19.7	....	...	....
Standing, attention, 10^h 45^m a. m.	12	18	248	268	.93	78	18.8	....	...	....
Apr. 3.										
Without food:										
Sitting, 8^h 46^m a. m.	15	20	219	245	.89	67	19.4	....	...	....
Standing, staff, 9^h 26^m a. m.	15	7	224	278	.81	77	19.1	....	...	....
Walking,[3] 10^h 33^m a. m.	13	43	771	903	.85	..	20.6	76.2	114	2.38
Food, 12^h 45^m p. m.:										
Walking,[3] 1^h 28^m p. m.	14	18	667	686	.97	..	23.4	57.0	100	2.02
Walking,[3] 2^h 28^m p. m.	14	7	894	938	.95	..	22.2	77.0	110	2.84
Walking,[3] 3^h 35^m p. m.	14	52	860	895	.96	..	22.8	78.9	112	3.38
Standing, 4^h 28^m p. m.	16	24	244	293	.83	81	22.0	....	...	....
Apr. 4.										
Food, 7^h 15^m a. m.:										
Walking,[4] 10^h 11^m a. m.	15	35	608	651	.93	[5]73	20.7	55.1	100	1.91
Walking,[4] 10^h 56^m a. m.	15	42	573	620	.92	[5]79	22.6	56.8	100	1.98
Walking,[4] 11^h 29^m a. m.	14	18	554	669	.83	..	21.3	56.2	99	1.87
Food, 1^h 15^m p. m.:										
Walking,[4] 2 p. m.	13	57	657	707	.93	..	23.3	54.4	101	2.05
Walking,[4] 2^h 55^m p. m.	15	45	705	755	.93	..	24.6	58.1	101	2.21
Apr. 6[6]										
Without food:										
Standing, 9^h 04^m a. m.	16	9	218	246	.89	[5]74	19.8	....	...	....
Walking,[7] 9^h 41^m a. m.	16	11	586	681	.86	[5]72	17.3	57.8	104	1.78
Walking,[7] 10^h 22^m a. m.	15	41	567	668	.85	[5]74	20.9	56.8	105	1.83
Walking,[7] 11^h 13^m a. m.	17	14	553	659	.84	[5]77	21.5	56.0	102	1.91
Protein, 12^h 55^m p. m.:										
Standing, 1^h 24^m p. m.	13	16	241	296	.82	..	19.2	....	...	....
Walking,[7] 1^h 46^m p. m.	15	59	631	725	.87	[5]78	19.4	57.5	105	2.21
Walking,[7] 2^h 24^m p. m.	14	36	641	712	.90	..	21.6	57.2	105	1.94
Walking,[7] 3^h 05^m p. m.	15	49	617	708	.87	[5]86	23.7	56.3	99	1.81

[1]Total distance before lunch, 1,085 meters; after lunch, 1,020 meters.

[2]Total distance preliminary to and during period, 1,164 meters.

[3]Total distance before lunch, 1,244 meters; after lunch, 7,296 meters. During about 43 minutes between the first two periods of the afternoon subject was not walking.

[4]Total distance before lunch, 5,207 meters; after lunch, 4,132 meters. The walking was continuous.

[5]Electrocardiograms were obtained during these periods by means of the string galvanometer.

[6]On and after Apr. 6, subject's food was prepared and eaten at the Laboratory.

[7]Total distance before lunch, 6,140 meters; after lunch, 5,433 meters. The walking, as was usually the case in the days that follow, was continuous.

TABLE 4.—*Summary of results in experiments with subject II, during period from Mar. 16, 1914, to May 15, 1914*—Continued.

[Values per minute.]

Date, condition, and time.	Duration.		Carbon dioxide.	Oxygen.	Respiratory quotient.	Average pulse-rate.	Average respiration-rate.	Distance.	Steps.	Raising of body.
Apr. 7.										
Without food:	*min.*	*sec.*	*c.c.*	*c.c.*				*meters.*		*meters.*
Standing, $9^h 18^m$ a. m.	14	29	214	257	0.83	[2]82	19.2	....	...	....
Walking,[1] $9^h 56^m$ a. m.	15	30	606	729	.83	[2]75	20.1	59.6	109	1.98
Walking,[1] $10^h 58^m$ a. m.	15	59	544	660	.82	[2]79	22.1	58.2	105	1.95
Standing, $11^h 27^m$ a. m.	14	8	198	235	.84	[2]90	21.4	....	...	....
Protein, $1^h 03^m$ p. m.:										
Standing, $1^h 31^m$ p. m.	13	23	217	289	.75	[2]88	19.6	....	...	....
Walking,[1] $2^h 07^m$ p. m.	16	19	643	732	.88	[2]81	20.4	58.8	107	1.78
Walking,[1] 3 p. m.	13	36	671	772	.87	[2]88	25.1	58.7	107	1.83
Walking,[1] $3^h 42^m$ p. m.	13	59	593	701	.85	..	24.5	56.9	99	1.82
Apr. 8.										
Without food:										
Standing, $9^h 10^m$ a. m.	14	6	204	265	.77	..	18.4	....	...	....
Walking,[3] $9^h 40^m$ a. m.	12	15	761	922	.82	..	21.0	76.1	121	3.01
Walking,[3] $10^h 14^m$ a. m.	14	22	662	826	.80	..	23.0	77.6	117	2.81
Walking,[3] $11^h 01^m$ a. m.	13	29	660	807	.82	..	24.4	78.3	113	2.85
Protein, 1 p. m.:										
Standing, $1^h 23^m$ p. m.	12	54	230	275	.83	..	19.1	....	...	....
Walking,[3] $2^h 01^m$ p. m.	13	22	785	869	.90	..	22.6	76.9	120	2.50
Walking,[3] $2^h 44^m$ p. m.	13	47	792	892	.89	..	25.7	78.0	117	3.01
Walking,[3] $3^h 30^m$ p. m.	13	1	782	917	.85	..	25.6	79.2	118	2.70
Apr. 9.										
Without food:										
Standing, $8^h 42^m$ a. m.	14	21	202	228	.89	82	18.7	....	...	....
Walking,[4] $9^h 22^m$ a. m.	15	15	590	701	.84	..	21.0	59.3	107	1.92
Walking,[4] $10^h 07^m$ a. m.	14	23	546	663	.82	..	22.5	58.8	105	2.05
Walking,[4] $10^h 47^m$ a. m.	14	34	568	697	.81	..	25.1	59.0	107	1.98
Carbohydrate, 1 p. m.:										
Standing, $1^h 19^m$ p. m.	12	42	245	295	.83	76	19.4	....	...	....
Walking,[4] $1^h 45^m$ p. m.	15	32	649	704	.92	..	22.9	59.4	107	1.95
Walking,[4] $2^h 26^m$ p. m.	13	48	646	691	.93	..	26.2	59.0	106	1.94
Walking,[4] $3^h 14^m$ p. m.	15	37	651	715	.91	..	26.1	58.8	104	1.94
Apr. 10.										
Without food:										
Standing, $8^h 54^m$ a. m.	13	39	212	257	.83	78	19.3	....	...	....
Walking,[5] $9^h 34^m$ a. m.	14	22	795	814	.98	..	22.6	77.3	120	2.77
Walking,[5] $10^h 57^m$ a. m.	12	46	712	841	.85	..	24.4	78.9	114	3.21
Carbohydrate, $12^h 08^m$ p. m.:										
Standing, $12^h 31^m$ p. m.	13	13	264	301	.88	86	21.1	....	...	....
Walking,[5] $1^h 16^m$ p. m.	13	23	879	948	.93	..	23.1	78.0	118	3.01
Walking,[5] $1^h 50^m$ p. m.	14	31	857	926	.93	..	26.0	79.1	116	3.17
Walking,[5] $2^h 30^m$ p. m.	14	25	823	881	.93	..	26.8	79.7	116	3.35
Apr. 14.										
Without food:										
Standing, $9^h 02^m$ a. m.	15	52	223	245	.91	94	19.0	....	...	....
Walking,[6] $9^h 48^m$ a. m.	13	51	630	695	.91	..	20.7	61.7	104	2.45
Walking,[6] $10^h 22^m$ a. m.	14	35	597	666	.90	..	23.6	62.1	103	2.34
Walking,[6] $11^h 06^m$ a. m.	14	59	563	672	.84	..	24.4	62.4	102	2.37

[1]Total distance before lunch, 5,007 meters; after lunch, 6,560 meters.
[2]Electrocardiograms were obtained during these periods by means of the string galvanometer.
[3]Total distance before lunch, 7,287 meters; after lunch, 7,933 meters.
[4]Total distance before lunch, 5,868 meters; after lunch, 6,141 meters.
[5]Total distance before lunch, 8,372 meters; after lunch, 7,221 meters.
[6]Total distance before lunch, 6,157 meters; after lunch, 6,062 meters.

TABLE 4.—*Summary of results in experiments with subject II, during the period from Mar. 16, 1914, to May 15, 1914*—Continued.

[Values per minute.]

Date, condition, and time.	Duration.		Carbon dioxide.	Oxygen.	Respiratory quotient.	Average pulse-rate.	Average respiration-rate.	Distance.	Steps.	Raising of body.
Apr. 14—Continued.										
Carbohydrate, 1 p. m.:[1]	*min.*	*sec.*	*c.c.*	*c.c.*				*meters.*		*meters.*
Standing, 1h 23m p. m.	14	32	242	295	0.82	90	19.5	....	...	....
Walking,[2] 1h 59m p. m.	14	15	681	674	1.01	..	23.4	61.2	102	2.38
Walking,[2] 2h 37m p. m.	15	36	672	711	.94	..	25.6	62.0	102	2.20
Walking,[2] 3h 15m p. m.	14	16	671	693	.97	..	25.9	62.2	104	2.27
Apr. 15.										
Without food:										
Standing, 8h 48m a. m.	15	41	214	252	.85	74	17.7	....	...	....
Walking,[3] 9h 30m a. m.	12	57	818	934	.88	..	22.7	77.2	119	3.33
Walking,[3] 10h 08m a. m.	15	19	696	829	.84	..	25.7	79.4	115	3.52
Walking,[3] 10h 53m a. m.	14	21	690	837	.82	..	25.4	80.2	114	3.49
Carbohydrate, 12h 52m p. m.:										
Standing, 1h 14m p. m.	14	1	267	277	.96	83	20.9	....	...	....
Walking,[3] 1h 52m p. m.	14	40	875	902	.97	..	26.4	78.2	117	3.88
Walking,[3] 2h 29m p. m.	14	54	859	878	.98	..	28.9	80.1	115	3.72
Walking,[3] 3h 05m p. m.	17	40	898	924	.97	..	28.9	80.6	117	3.88
Apr. 16.										
Without food:										
Standing, 8h 32m a. m.	14	55	...	258	...	90	19.5	....	...	....
Walking,[4] 9h 14m a. m.	15	22	568	644	.88	..	21.0	61.9	105	2.38
Walking,[4] 9h 53m a. m.	12	34	544	668	.81	..	24.4	62.3	106	2.37
Walking,[4] 10h 36m a. m.	14	2	553	661	.84	..	25.1	61.8	106	2.20
Fat, 11h 30m a. m.:										
Standing, 12h 03m p. m.	14	10	239	292	.82	98	19.8	....	...	....
Walking,[4] 12h 44m p. m.	14	13	600	683	.88	..	23.4	61.6	107	2.49
Walking,[4] 1h 20m p. m	15	31	593	635	.93	..	25.7	62.3	105	2.48
Walking,[4] 2h 14m p. m	15	53	611	701	.87	..	26.2	62.2	105	2.24
Walking,[4] 3h 10m p. m	18	8	586	707	.83	..	25.0	61.9	103	2.21
Apr. 17.										
Without food:										
Standing, 8h 31m a. m.	14	22	214	265	.81	85	20.9	....	...	....
Walking,[5] 9h 08m a. m.	13	48	773	895	.86	..	23.8	76.6	118	3.36
Walking,[5] 9h 50m a. m.	14	58	672	816	.82	..	24.6	78.1	117	3.45
Walking,[5] 10h 37m a. m.	14	39	693	862	.80	..	26.8	79.3	117	3.80
Fat, 11h 30m a. m.:										
Standing, 12h 09m p. m.	16	18	231	281	.82	99	20.5	....	...	....
Walking,[5] 12h 48m p. m.	14	49	715	832	.86	..	23.5	77.6	118	3.96
Walking,[5] 1h 34m p. m.	13	20	735	883	.83	..	26.8	79.5	117	3.78
Walking,[5] 2h 18m p. m.	14	11	799	938	.85	..	27.9	80.0	119	3.85
Walking,[5] 3h 17m p. m.	16	15	721	856	.84	..	27.2	80.0	115	3.67
Apr. 21.										
Without food:										
Standing, 10h 25m a. m.	13	59	205	242	.85	78	19.1	....	...	....
Walking,[6] 11h 16m a. m.	15	50	562	639	.88	..	22.8	60.8	105	2.32
Fat, 12h 30m p. m.:										
Standing, 1h 03m p. m.	12	33	220	301	.73	91	19.7	....	...	....
Walking,[6] 1h 45m p. m.	14	13	590	683	.86	..	21.8	60.4	104	2.45
Walking,[6] 2h 25m p. m.	14	55	624	699	.89	..	25.2	60.6	104	2.56
Walking,[6] 3h 10m p. m.	14	17	608	705	.86	..	25.8	60.5	103	2.34
Walking,[6] 4h 01m p. m.	16	12	592	709	.83	..	25.4	60.5	105	2.23

[1]Subject did not eat so much as on other days.
[2]Total distance before lunch, 6,157 meters; after lunch, 6,062 meters.
[3]Total distance before lunch, 8,306 meters; after lunch, 7,657 meters.
[4]Total distance before lunch, 6,350 meters; after lunch, 10,547 meters.
[5]Total distance before lunch, 8,680 meters; after lunch, 13,566 meters.
[6]Total distance preliminary to and during period before lunch, 1,651 meters; after lunch, 9,494 meters.

TABLE 4.—*Summary of results in experiments with subject II, during period from Mar. 16, 1914, to May 15, 1914*—Continued.

[Values per minute.]

Date, condition, and time.	Duration.		Carbon dioxide.	Oxygen.	Respiratory quotient.	Average pulse-rate.	Average respiration-rate.	Distance.	Steps.	Raising of body.
Apr. 22.										
Without food:	*min.*	*sec.*	*c.c.*	*c.c.*				*meters.*		*meters.*
Standing, 8^h 39^m a. m.	14	20	207	251	0.83	84	18.0	....	...	....
Walking,[1] 9^h 27^m a. m.	15	17	687	804	.85	..	23.5	76.8	118	3.33
Walking,[1] 10^h 09^m a. m.	13	26	655	829	.79	..	26.1	78.6	118	3.44
Walking,[1] 10^h 44^m a. m.	13	48	647	822	.79	..	25.7	79.2	115	3.42
Fat, 11^h 40^m a. m.:										
Standing, 12^h 14^m p. m.	14	11	227	299	.76	93	20.8	....	...	....
Walking,[1] 12^h 55^m p. m.	14	30	725	833	.87	..	26.0	77.3	116	3.86
Walking,[1] 1^h 34^m p. m.	13	37	729	877	.83	..	28.7	78.7	118	3.86
Walking,[1] 2^h 20^m p. m.	13	18	737	877	.84	..	28.4	79.5	118	3.92
Walking,[1] 3^h 01^m p. m.	14	03	739	858	.86	..	28.4	79.7	116	3.84
Apr. 23.										
Without food:										
Standing, 8^h 40^m a. m.	15	57	208	252	.82	74	19.3	....	...	....
Walking,[2] 9^h 34^m a. m.	15	23	561	675	.83	..	20.5	61.1	105	2.53
Walking,[2] 10^h 15^m a. m.	16	37	528	660	.80	..	24.2	....	105	2.46
Protein, 11^h 10^m a. m.:										
Standing, 11^h 40^m a. m.	14	7	223	254	.88	81	20.1	....	...	....
Walking,[2] 12^h 24^m p. m.	13	0	644	722	.89	..	19.7	61.2	106	2.74
Walking,[2] 1^h 03^m p. m.	13	18	607	705	.86	..	24.6	61.6	105	2.57
Walking,[2] 1^h 47^m p. m.	13	56	606	707	.86	..	25.0	61.6	104	2.48
Walking,[2] 2^h 28^m p. m.	15	5	605	707	.86	..	24.3	61.7	103	2.63
Apr. 24.										
Without food:										
Standing, 9^h 14^m a. m.	12	43	198	...	...	82	18.7	....	...	....
Walking,[3] 9^h 55^m a. m.	14	31	635	790	.80	..	21.4	76.4	116	3.60
Walking,[3] 10^h 26^m a. m.	12	24	636	828	.77	..	25.8	78.4	117	3.69
Protein, 11^h 15^m a. m.:										
Standing, 11^h 58^m a. m.	14	19	219	299	.73	94	20.3	....	...	....
Walking,[3] 12^h 35^m p. m.	14	21	699	835	.84	..	22.9	77.0	114	3.74
Walking,[3] 1^h 07^m p. m.	13	9	695	853	.81	..	26.3	78.8	115	3.88
Walking,[3] 1^h 42^m p. m.	13	54	704	890	.79	..	26.3	80.0	115	3.84
Walking,[3] 2^h 15^m p. m.	14	0	712	880	.81	..	25.4	80.0	115	3.88
Apr. 25.										
Without food:										
Standing, 9^h 30^m a. m.	12	59	192	264	.73	79	19.6	....	...	....
Walking,[4] 10 a. m.	13	24	543	665	.82	..	20.2	63.0	105	2.65
Walking,[4] 10^h 33^m a. m.	13	25	531	695	.76	..	23.3	64.0	107	2.69
Carbohydrate, 11^h 20^m a. m.:										
Standing, 11^h 49^m a. m.	12	21	274	324	.85	83	20.6	....	...	....
Walking,[4] 12^h 25^m p. m.	14	37	668	708	.94	..	22.2	63.1	104	2.88
Walking,[4] 12^h 56^m p. m.	17	17	662	711	.93	..	24.4	63.8	105	2.70
Walking,[4] 1^h 40^m p. m.	15	23	688	694	.99	..	25.7	63.7	106	2.85
Walking,[4] 2^h 30^m p. m.	15	13	641	669	.96	..	25.2	63.3	104	2.64

[1]Total distance before lunch, 7,548 meters; after lunch, 11,466 meters.
[2]Total distance before lunch, about 4,300 meters; after lunch, 8,908 meters.
[3]Total distance before lunch, 3,888 meters; after lunch, 9,414 meters.
[4]Total distance before lunch, 3,216 meters; after lunch, 9,089 meters.

TABLE 4.—*Summary of results in experiments with subject II, during period from Mar. 16, 1914, to May 15, 1914*—Continued.

[Values per minute.]

Date, condition, and time.	Duration.		Carbon dioxide.	Oxygen.	Respiratory quotient.	Average pulse-rate.	Average respiration-rate.	Distance.	Steps.	Raising of body.
Apr. 27.										
Without food:	*min.*	*sec.*	*c.c.*	*c.c.*				*meters.*		*meters.*
Standing, 9^h 10^m a. m.	13	52	217	245	0.89	77	20.5	....	...	....
Walking,[1] 9^h 48^m a. m.	13	54	681	767	.89	..	23.3	73.5	115	3.25
Walking,[1] 10^h 20^m a. m.	12	26	679	821	.83	..	26.5	78.1	116	3.64
Carbohydrate, 11^h 10^m a. m.:										
Standing, 11^h 34^m a. m.	13	50	294	326	.90	75	21.0	....	...	....
Walking,[1] 12^h 12^m p. m.	14	22	845	854	.99	..	24.7	77.5	116	3.60
Walking,[1] 12^h 45^m p. m.	13	29	837	797	1.05	..	27.5	78.9	115	3.56
Walking,[1] 1^h 21^m p. m.	15	43	886	840	1.05	..	28.6	79.8	116	3.88
Walking,[1] 2^h 08^m p. m.	15	32	850	801	1.06	..	27.6	80.2	116	3.74
Apr. 28.										
Without food:										
Standing, 8^h 39^m a. m.	12	30	221	274	.81	82	19.6	....	...	....
Walking,[2] 9^h 12^m a. m.	15	53	713	828	.86	..	23.0	78.2	118	3.41
Walking,[2] 9^h 48^m a. m.	13	4	699	820	.85	..	26.4	79.8	116	3.60
Walking,[2] 10^h 26^m a. m.	13	20	680	846	.80	..	26.1	80.0	116	3.53
Walking,[2] 11^h 07^m a. m.	13	52	689	858	.80	..	26.5	80.7	118	3.80
Walking,[2] 11^h 51^m a. m.	15	20	716	925	.77	..	27.4	80.4	121	3.33
Walking,[2] 12^h 33^m p. m.	14	44	657	854	.77	..	27.2	80.2	116	3.67
Walking,[2] 1^h 06^m p. m.	14	43	682	865	.79	..	28.1	80.2	119	3.80
Walking,[2] 1^h 49^m p. m.	15	8	659	859	.77	..	27.8	80.4	116	3.46
Apr. 29.										
Carbohydrate, 8^h 35^m a. m.:										
Walking,[3] 9^h 08^m a. m.	14	8	817	864	.95	..	27.1	76.9	114	3.63
Walking,[3] 9^h 45^m a. m.	14	26	789	863	.91	..	27.2	78.2	114	3.56
Walking,[3] 10^h 24^m a. m.	14	11	817	839	.97	..	27.8	79.5	114	3.52
Walking,[3] 11^h 04^m a. m.	14	42	797	810	.98	..	26.9	80.9	117	3.74
Walking,[3] 11^h 40^m a. m.	14	25	777	823	.94	..	26.6	81.1	116	3.76
Walking,[3] 12^h 18^m p. m.	13	42	696	790	.88	..	27.2	80.9	115	3.29
Walking,[3] 12^h 58^m p. m.	14	56	704	848	.83	..	26.9	81.0	120	3.73
Walking,[3] 1^h 35^m p. m.	15	19	666	830	.80	..	27.1	81.1	116	3.69
May 4.										
Without food:										
Walking,[4] 9^h 27^m a. m.	10	38	1183	1377	.86	..	25.1	114.5	138	6.43
Walking,[4] 10^h 02^m a. m.	11	9	1052	1175	.90	..	27.7	109.1	134	6.16
Walking,[4] 10^h 35^m a. m.	11	26	934	1117	.84	..	26.9	102.0	128	5.88
Carbohydrate, 11^h 19^m a. m:										
Walking,[4] 12^h 02^m p. m.	10	34	1212	1336	.91	..	27.1	113.4	134	6.84
Walking,[4] 12^h 43^m p. m.	11	23	1237	1295	.95	..	28.6	112.3	131	7.88
Walking,[4] 1^h 16^m p. m.	10	56	1177	1221	.96	..	28.6	110.3	128	7.41

[1]Total distance before lunch, 3,793 meters; after lunch, 10,612 meters.

[2]Total distance in about 5 hours of continuous walking, 23,697 meters. Pulse-rate of subject standing during 5 consecutive minutes immediately after walking, 100, 98, 96, 96, and 98 per minute.

[3]Total distance in 4 hours and 52 minutes of continuous walking, 22,919 meters. Pulse-rate during 4 minutes soon after the carbohydrate breakfast averaged 73 per minute with the subject sitting; during 4 consecutive minutes immediately after walking it was 80, 79, 80, and 79 per minute, with subject standing.

[4]Total distance before lunch, 6,949 meters; for about 20 minutes after the first period subject was not walking. After lunch, the distance was 9,362 meters.

TABLE 4.—*Summary of results in experiments with subject II, during the period from Mar. 16, 1914, to May 15, 1914*—Continued.

[Values per minute.]

Date, condition, and time.	Duration.		Carbon dioxide.	Oxygen.	Respiratory quotient.	Average pulse-rate.	Average respiration-rate.	Distance.	Steps.	Raising of body.
May 5.										
Without food:	*min.*	*sec.*	*c.c.*	*c.c.*				*meters.*		*meters.*
Standing, 8h 24m a. m.	13	7	229	277	0.83	83	19.7	....	...	....
Walking,[1] 9h 42m a. m.	10	3	1011	1124	.90	..	25.5	106.0	133	4.86
Walking,[1] 10h 11m a. m.	11	5	915	1101	.83	..	28.0	102.6	127	5.82
Walking,[1] 10h 44m a. m.	10	3	909	1151	.79	..	28.0	103.6	126	6.06
Protein, 11h 31m a. m.:										
Walking,[1] 11h 57m a. m.	9	25	1135	1298	.87	..	28.8	112.6	133	7.69
Walking,[1] 12h 30m p. m.	10	39	1137	1318	.86	..	29.0	113.7	133	7.83
Walking,[1] 1h 13m p. m.	10	32	1035	1208	.86	..	28.5	106.0	128	6.40
Walking,[1] 1h 46m p. m.	9	31	1076	1307	.82	..	29.2	111.3	129	7.76
May 6.										
Without food:										
Walking,[2] 9h 08m a. m.	8	55	1902	2068	.92	..	31.1	140.7	149	9.76
Walking,[2] 10h 31m a. m.	9	30	1848	2125	.87	..	33.4	139.6	148	8.90
Walking,[2] 11h 15m a. m.	8	12	1796	2279	.79	..	35.1	142.9	152	8.79
Carbohydrate, 11h 40m a. m.:										
Walking,[2] 12h 45m p. m.	8	36	2058	2147	.96	..	35.5	143.0	145	7.82
May 10.										
Without food:										
Standing, 8h 34m a. m.	11	5	215	246	.87	74	18.4	....	...	....
Walking,[3] 9h 44m a. m.	8	22	2017	2232	.90	..	32.8	145.5	153	5.37
Walking,[3] 10h 47m a. m.	8	14	2101	2384	.88	..	38.6	146.8	157	6.59
Walking,[3] 11h 33m a. m.	9	2	2006	2234	.90	..	37.1	146.6	154	8.02
Protein, 12h 15m p. m.:										
Walking,[3] 12h 43m p. m.	8	14	2017	2244	.90	..	36.0	146.5	157	7.83
Walking,[3] 1h 20m p. m.	8	15	2020	2249	.90	..	40.1	146.9	156	8.28
May 11.										
Without food:										
Standing, 8h 37m a. m.	12	47	259	278	.93	85	20.9	....	...	....
Standing, swinging arms,[4] 9h 16m a. m.	10	52	455	516	.88	..	20.9	....	...	....
Running,[5] 10h 01m a. m.	8	19	1850	1886	.98	..	35.7	146.6	184	13.45
Running,[5] 10h 49m a. m.	8	55	1755	1938	.91	..	36.8	146.7	183	13.89
Running,[5] 11h 35m a. m.	8	24	1793	1964	.91	..	37.9	148.3	181	14.80
Carbohydrate, 12 noon:										
Running,[5] 12h 44m p. m.	8	23	1795	1910	.94	..	36.6	148.7	181	13.95

[1]Total distance before lunch, 8,126 meters; after lunch, 9,193 meters. During about 40 minutes of the intervals between periods in the afternoon, subject was not walking but sitting.

[2]Total distance before lunch, 5,571 meters; after lunch, 1,543 meters. Subject perspired very much with this rate of walking and worked with arms and hands much more than at the other speeds. For about 1 hour and 40 minutes of the intervals between periods in the morning he was not walking.

[3]Total distance before lunch, 6,307 meters; after lunch, 3,468 meters. During about 1 hour and 20 minutes of the intervals between periods in the morning and about 25 minutes in the afternoon, subject was sitting or walking a little in the room.

[4]The subject swung his arms as vigorously as in the fastest walking.

[5]Total distance before lunch, 5,595 meters; after lunch, 1,729 meters. In running, the subject held arms up in front of body and the only movement of the arms was that of the swaying body. During about 1 hour and 10 minutes of the intervals between periods in the morning subject was not running.

TABLE 4—*Summary of results in experiments with subject II, during period from Mar. 16, 1914, to May 15, 1914*—Concluded.

[Values per minute.]

Date, condition, and time.	Duration.		Carbon dioxide.	Oxygen.	Respiratory quotient.	Average pulse-rate.	Average respiration-rate.	Distance.	Steps.	Raising of body.
May 12.										
Without food:	*min.*	*sec.*	*c.c.*	*c.c.*				*meters.*		*meters.*
Standing, 9h 01m a. m.	13	15	226	293	0.77	82	20.4	....	...	....
Running,[1] 9h 45m a. m.	8	19	1983	2194	.90	..	34.9	147.1	191	15.40
Running,[1] 10h 44m a. m.	8	55	1758	1843	.95	..	37.8	148.4	183	14.09
Running,[1] 11h 38m a. m.	8	28	1723	2011	.86	..	39.2	148.1	182	15.40
Running,[1] 12h 26m p. m.	10	12	1752	2050	.85	..	39.2	148.1	184	14.64
Running,[1] 1h 10m p. m.	10	6	1734	2080	.83	..	40.8	148.7	176	15.37
May 13.										
Without food:										
Standing, 10h 20m a. m.	12	27	213	257	.83	79	20.2	....	...	....
Walking,[2] 11h 08m a. m.	13	30	711	851	.84	..	25.9	82.6	117	3.76
Walking,[2] 11h 47m a. m.	12	49	734	942	.78	..	27.9	89.7	120	4.51
Walking,[2] 12h 31m p. m.	12	1	639	826	.77	..	27.0	80.1	112	3.29
Walking,[2] 1h 16m p. m.	13	10	597	789	.76	..	25.4	76.6	106	2.84
Walking,[2] 2h 18m p. m.	12	29	757	998	.74	..	28.0	93.3	117	5.25
Walking,[2] 3h 06m p. m.	13	2	753	980	.77	..	28.5	91.9	118	5.15
May 14.										
Without food:										
Standing, 8h 32m a. m.	13	53	209	257	.81	80	20.0	....	...	....
Walking,[3] 9h 33m a. m.	7	41	2046	2281	.90	..	38.6	146.4	153	7.59
Running,[3] 10h 28m a. m.	7	58	1997	2272	.88	..	37.5	146.5	168	15.44
Running,[3] 11h 20m a. m.	8	51	1646	1867	.88	..	38.3	147.2	183	12.47
Running,[3] 11h 58m a. m.	9	2	1625	1900	.86	..	38.8	147.6	182	12.34
Running,[3] 12h 35m p. m.	9	41	1701	1982	.86	..	40.1	148.1	183	11.09
May 15.										
Without food:										
Standing, swinging arms,[4] 8h 52m a. m.	12	8	554	643	.86	..	22.3	....	...	....
Running,[5] 9h 57m a. m.	9	40	1735	1967	.88	..	38.6	144.7	182	12.48
Running,[5] 10h 37m a. m.	8	45	1727	1978	.87	..	37.3	148.4	183	12.14
Running,[5] 11h 21m a. m.	8	20	1647	1947	.85	..	38.9	147.7	184	13.13

[1]The total distance was 10,111 meters. During $2\frac{1}{2}$ hours of the intervals between periods subject was sitting or walking a little in the room.

[2]Total distance, 21,724 meters, the walking being continuous.

[3]Total distance, walking and running, 9,432 meters. During about 2 hours and 11 minutes of the intervals between periods, subject was sitting or standing.

[4]Subject swung his arms as vigorously as in the fastest walking.

[5]Total distance, 5,711 meters. During about 58 minutes of the intervals between periods, subject was not running or walking.

DISCUSSION OF RESULTS.

BASAL VALUES.

In any study of walking in a horizontal direction, two main problems present themselves: first, the variations in the energy requirement of different individuals for walking varying distances at varying velocities, and second, the actual energy requirement for transporting the body-weight or a superimposed load in a horizontal direction, *i. e.*, the calorie output per horizontal kilogrammeter.

As has already been noted, the mechanical processes incidental to walking, even at a moderate pace, usually involve some extraneous muscular movements apparently not directly connected with the motion of forward progression, such as the more or less vigorous swinging of the arms and a not inconsiderable raising of the body-weight with each step. Since these extraneous muscular movements do not necessarily have an effective value in transporting the body-weight or the superimposed load in a horizontal direction, the problem of finding the calorie requirement for such transportation of weight becomes an exceedingly complicated one.

If the principle of the deduction of basal values for determining the energy required to move 1 kilogram 1 meter in a horizontal direction may be legitimately employed, and this has been the method adopted by all investigators, it becomes an important point as to what should properly be considered as the basal maintenance metabolism in experiments when the subject is walking in a horizontal direction. As will be seen by reference to the summary of previous researches given in table 1, investigators have varied considerably in their usage in this respect. Certain members of the Zuntz school have almost invariably employed the resting (lying) metabolism obtained with the subject in the post-absorptive condition. The values found with the subject sitting or standing quietly have also been used as a basis in determining the metabolism due to the muscular activity of walking. Still another basal value which may be considered is that found when the subject is standing and moving his arms in a manner similar to that employed in more or less rapid walking. Finally it may even be possible to use the metabolism determined during slow walking for a basal value to be deducted from the metabolism found while the subject was walking at a rapid rate. The validity of this assumption will be examined later.

Bearing in mind the experience of Benedict and Cathcart in attempting to secure a suitable base-line for their bicycle rider, we considered it desirable to study our subjects in varying positions. The positions selected have been outlined in a preceding section. Since we were to make a large number of observations upon each subject, we concluded that the period of adjustment to the type of the experiment would be so short that a moderately constant value could be found in the standing position, and hence the greater part of our control data was obtained in experiments with the subject standing in a relaxed position. Although values for comparison are available for other standing positions and for the subject sitting, no studies were made by us with the subject in complete muscular repose, *i. e.*, lying upon a couch, in the post-absorptive condition.

Obviously it is first necessary to examine the data thus secured to determine the suitable basal values to be deducted from the total metabolism while walking, such a critical examination being of fundamental importance. Since the total metabolism is made up of that for maintenance, *i. e.*, the basal value plus that for forward progression, it is evident that the larger the value deducted for maintenance—as, for instance, the value obtained with the subject standing as compared with the subject lying on a couch—the smaller will be the result obtained for the energy requirement for the work of forward progression.

BASAL METABOLISM OF SUBJECT I.

As a result of a consideration of the experimental experience of others, it was decided that in the preliminary observations in this investigation, which were made with subject I by Dr. Carl Tigerstedt, the basal value selected should be that necessary for maintenance while the subject was standing quietly without support. Accordingly, during November and December 1913 many observations were made of the subject in this position. Subsequently it appeared that more information was desirable with regard to the normal increment in metabolism due to a change from the lying position to the standing position, but as a study of this phase of the question was wholly incidental to the main problem of the metabolism during forward progression, the experimental routine did not permit such observations. We have, however, the results of a study made in December 1914 by Mr. H. L. Higgins, of the Laboratory staff, upon the lying and standing metabolism of subject I, which were kindly supplied us for comparison with our values. Unfortunately the data thus obtained are more or less fragmentary and must therefore be considered as only subsidiary to the results of the larger investigation.

The Thiry valves and Tissot spirometer and mouthpiece were used in this study, both the resting metabolism and the standing metabolism being observed with the subject in the post-absorptive condition. We have no data as to the influence of food upon the resting metabolism of this subject. The results obtained by Mr. Higgins are recorded in table 5. These values are typical of a large number secured by this observer in another research with subject I, who shows a remarkably uniform basal resting metabolism. As will be seen from the table, the heat output per minute of this individual in the lying position was on December 2 and 5, 1914, 1.23 and 1.22 calories respectively.

The values found by Dr. Carl Tigerstedt for subject I in the standing position, which was the only position used by Dr. Tigerstedt in determining the basal metabolism of this subject, are given in table 6. Since the walking experiments were made in the morning and in the afternoon and with and without food, the basal values were also obtained in both the post-absorptive condition and after the taking of food. The apparatus used for determining the respiratory exchange was the same as that employed for the walking experiments.

TABLE 5.—*Metabolism of subject I in the lying and standing positions in experiments without food, on Dec. 2 and Dec. 5, 1914.*

[Observations made by Mr. H. L. Higgins with Thiry valves and Tissot spirometer. Values per minute.]

Date and time.	Duration.	Carbon dioxide.	Oxygen.	Heat output (computed).	Pulse-rate.	Respiration-rate.
Dec. 2.	*mins.*	*c.c.*	*c.c.*	*cals.*		
Lying, 8^h 53^m a. m.	10	210	249	....	62	22.0
Standing, 9^h 13^m a. m.	8	230	297	....	84	....
Standing, 9^h 29^m a. m.	8	224	287	....	85	25.7
Lying, 10^h 15^m a. m.	10	208	256	....	61	24.8
Lying, 10^h 35^m a. m.	10	196	262	....	61	24.1
Average, lying	..	205	256	1.23	61	23.6
Average, standing	..	227	292	1.39	84	25.7
Dec. 5.						
Lying, 9^h 02^m a. m.	10	219	246	....	62	23.4
Standing, 9^h 27^m a. m.	8	220	269	....	95	25.8
Standing, 9^h 44^m a. m.	8	217	268	....	90	26.4
Lying, 10^h 25^m a. m.	9	221	249	....	57	24.8
Average, lying	..	220	248	1.22	60	24.1
Average, standing	..	219	269	1.29	93	26.1

As will be seen from table 6, the average post-absorptive values are reasonably constant throughout the entire period from November 28 to December 20. A striking exception is shown on December 5, when the average carbon-dioxide excretion was 236 c.c. per minute and the oxygen consumption 334 c.c. per minute. The protocols for this experiment show that "there was no sleep the night before, but much alcohol." The pulse-rate was especially high on this particular day. The general average for the observations without food shows a carbon-dioxide excretion of 223 c.c. per minute and an oxygen consumption of 280 c.c. per minute. This corresponds to a heat output of 1.34 calories per minute. The pulse-rate of this man was extremely high, averaging 94 beats per minute; the average respiration rate was 21.2 per minute.

All of these experiments were made with subject I standing with muscles relaxed. The general uniformity of the data shows that for the most part the subject must have assumed a standing position with a relatively constant muscle strain, although variations are found in the experiments without food from 1.28 to 1.57 calories per minute. Excluding the extraordinarily high value of December 5, which is at least in part explained by the alcoholic excesses of the preceding night, the uniformity in the average values is for the most part striking. It is also of interest to note that the average value obtained for all of the standing experiments without food during December 1913, *i. e.*, 1.34 calories, is the same as that of the average of two standing experiments made by Mr. Higgins in December 1914. (See table 5.) It will be seen, therefore, that for many purposes an average basal value may be used for this subject with propriety and that it may be assumed that when standing quietly and in the post-absorptive condition, his average heat output would correspond to 1.34 calories per minute.

TABLE 6.—*Metabolism of subject I in the standing position.*
[Observations made by Dr. Carl Tigerstedt. Average values per minute.]

Date.	Carbon dioxide.	Oxygen.	Heat-output (computed).	Pulse-rate.	Respiration-rate.
1913.					
Without food:	*c.c.*	*c.c.*	*cals.*		
Nov. 28	222	285	1.36	92	17.1
29	224	282	1.35	93	18.5
Dec. 1	220	279	1.34	92	19.3
2	224	286	1.37	89	20.7
3	214	272	1.30	92	21.8
4	214	267	1.28	90	22.6
5	236	334	1.57	105	23.2
8	206	271	1.29	91	21.2
15	222	275	1.32	89	22.2
16	223	286	1.37	101	22.2
17	223	271	1.31	91	21.3
18	229	263	1.29	86	21.3
19	239	279	1.36	98	23.0
20	226	270	1.31	103	22.9
Average, without food	223	280	1.34	94	21.2
After breakfast:					
Nov. 26	281	332	1.61	..	....
Dec. 9	248	341	1.61	112	22.9
After dinner:					
Nov. 26	273	335	1.61	84	18.2
Average, with food	267	336	1.61	98	19.8

When the superimposed factor in a metabolism experiment is sufficiently great to increase the metabolism several hundred per cent, as is especially the case in muscular-work experiments, the use of a previously established average basal value is least liable to objection. Although with this particular subject we may assume that we have a fairly well-established basal value, as a matter of fact, to eliminate possible wide variations we rarely used this average figure and the absolutely determined basal value for each day, which was usually available, was given the preference.

INFLUENCE OF FOOD AND BODY POSITION.

In this preliminary study of subject I, we have two main factors to be considered, namely, the influence of food and of body position.

Influence of food.—We have only three experiments in which observations were made of the standing metabolism of subject I after the ingestion of food. Singularly enough, the average on each of these three days shows that the heat output after the ingestion of food when measured with the subject in the standing position was the same in all of the experiments, *i. e.*, 1.61 calories. (See table 6.) As we have no basal value without food which was determined on these three days, we must be content to note that the average basal value of 1.34 calories was increased 0.27 calorie per minute as the result of the ingestion of food, an increment of approximately 20 per cent. It is thus clear that prior to the actual walking tests after meals, the subject has a noticeably larger basal metabolism than prior to the walking experiments in the morning in the post-absorptive condition. The intelligent use of these basal values after food is a subject of subsequent discussion.

Influence of position.—In his experiments with subject I in December 1914, Mr. Higgins also obtained data regarding the metabolism of this subject in the standing position. Any comparison of these values with those obtained by us a year earlier for the same position would be a violation of a fundamental principle in the computation of metabolism experiments, notwithstanding the facts that the difference in the body weight is but 2 kilograms and that the values obtained for the metabolism in both cases were extraordinarily constant. Nevertheless, in the hope of throwing some light on the probable increment in the metabolism to be expected from this man, when standing, we have included in table 5 (page 63) Mr. Higgins's results of December 1914 for the standing position.

The observations on December 2 show an average heat output for the standing position of 1.39 calories per minute, but three days later (December 5), when the conditions were apparently identical, the heat output was but 1.29 calories per minute. Using the average values for the resting (lying) metabolism on the same days, we note an increase in the heat output on December 2 from 1.23 calories to 1.39 calories and on December 5 from 1.22 calories to 1.29 calories, the average increase being from 1.225 calories to 1.34 calories. This is equivalent to an average increment of 0.115 calorie, or approximately 9 per cent, due to the changing of the position from lying to standing. Since the average value of 1.225 calories for the metabolism in the lying position is true not only for the two days referred to but also for an extensive series of experiments made by Mr. Higgins on this subject in 1914, and since the average of the two standing experiments made by the same observer is identical with the average of the long series of standing experiments made one year previous by Dr. Tigerstedt, we may properly maintain that with this subject a change in the body position from lying to standing is accompanied by an increase of approximately 9 per cent in the total metabolism.

BASAL METABOLISM OF SUBJECT II.

With the beginning of the prolonged research on the professional athlete subject II (the bicycle-riding subject M. A. M. of Benedict and Cathcart), we planned definitely to secure much more extended data as to the metabolism during various standing positions, to supplement the preliminary data obtained with subject I by observations made on subject II after the ingestion of food, and to determine in addition the metabolism of the subject in the sitting position. These studies were wholly incidental to the main problem of studying the motion of forward progression and were made primarily with a view to illuminating the possible selection of the most advantageous and the most scientifically sound base-lines. At the time the observations were made, we were not certain of their ultimate use in the final computations, so they may properly be considered as a study of the metabolism in the standing and sitting positions, with and without food.

METABOLISM IN THE LYING POSITION.

The observation of the post-absorptive metabolism of this subject in the lying position was confined to one experiment which was made through the kindness of Mr. L. E. Emmes, of the Laboratory staff, but a large number of basal values for this position were also available as a result of the previous study of the subject by Cathcart. The results obtained in the experiment made by Mr. Emmes and an average value for the results obtained by Cathcart are given in table 7.

TABLE 7.—*Metabolism of subject II in the lying position in experiments without food.*
[Observations made by Mr. L. E. Emmes. Values per minute.]

Date and time.	Carbon dioxide.		Oxygen.		Heat-output (computed).	Pulse-rate.	Respiration-rate.
	Total.	Per kilogram.	Total.	Per kilogram.			
Apr. 18, 1914:[1]	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*cals.*		
8h 24m a. m.	198	....	226	....	....	57	15.5
8 54 a. m.	186	....	229	....	....	56	15.5
9 17 a. m.	196	....	229	....	....	58	16.5
9 48 a. m.	193	....	232	....	....	56	16.3
Average.	193	2.86	229	3.39	1.11	57	15.9
Dec. 7, 1911, to Apr. 16, 1912[2]	205	3.12	242	3.67	1.17	63	20.0

[1]The duration of each period on April 18 was about 15 minutes and 3 seconds.
[2]Average of experiments made by Benedict and Cathcart. See Carnegie Inst. Wash. Pub. 187, 1913, p. 78.

The four periods of the respiration experiment made on April 18, 1914, by Mr. Emmes show an excellent agreement which is characteristic of this subject. Although his nude body-weight was 1.6 kilograms greater than at the time of the study of Cathcart, being 67.5 kilograms on April 18, 1914, and averaging 65.9 kilograms during the previous research, the heat output per minute was but 1.11 calories per kilogram per minute as compared to the average of the earlier observations of 1.17 calories per kilogram per minute. While it is possible that direct averaging in this instance is a mathematically unsound procedure, we may state that the resting basal heat output of subject II in the post-absorptive state may be considered to be, in round numbers, 1.14 calories.

METABOLISM IN THE SITTING POSITION.

In a further effort to secure all possible data for establishing various scientifically sound base-lines, we made a special study of the metabolism of subject II while he sat comfortably in a chair. Three observations were made with the subject in the post-absorptive condition, four after a light breakfast, and five after a heavier midday meal. The data are sufficiently extended to permit their classification according to the character of the meal and such a classification is used in presenting the results of the study of the sitting metabolism in table 8.

TABLE 8.—*Metabolism of subject II in the sitting position.*
[Values per minute.]

Date.	Carbon dioxide.	Oxygen.	Heat-output (computed).	Pulse-rate.	Respiration-rate.
1914					
Without food:	*c.c.*	*c.c.*	*cals.*		
Mar. 25	192	260	1.23	59	18.0
27	195	234	1.13	58	17.6
Apr. 3	219	245	1.20	67	19.4
Average	202	246	1.19	61	18.3
After light meal:					
Mar. 16	218	281	1.34	..	18.7
16	203	256	1.23	..	18.3
18	233	286	1.38	..	19.2
19	242	282	1.37	67	18.7
Average	224	276	1.33	..	18.7
After heavy meal:					
Mar. 16	250	304	1.47	..	19.9
17	213	272	1.30	..	18.1
18	248	297	1.44	..	19.3
19	259	322	1.55	77	21.0
25	272	316	1.54	73	19.6
Average	248	302	1.46	..	19.6

With subject I no such classification could properly be made and, indeed, the observations after the ingestion of food were but few in number.

The metabolism with and without food are further compared in table 9, to which is added the actual increase in the units of measurement commonly employed for the various factors and the percentage increase. From this table we see that as the result of a light meal the carbon dioxide was increased 10.9 per cent, the oxygen consumption 12.2 per cent, and the heat output 11.8 per cent. After the heavy meal, the percentage increase was essentially the same for all three factors, *i. e.*, 22.8 per cent. This percentage increment in the metabolism of subject II after a heavy meal is almost identical with that noted for subject I in the few experiments made with him.

TABLE 9.—*Metabolism of subject II in the sitting position with and without food.*
[Average values per minute.]

Condition.	Carbon dioxide.	Oxygen.	Heat output (computed).	Pulse-rate.	Respiration-rate.
	c.c.	*c.c.*	*cals.*		
Without food	202	246	1.19	61	18.3
After light meal	224	276	1.33	[1]67	18.7
Increase with food	22 10.9 p. ct.	30 12.2 p. ct.	.14 11.8 p. ct.	6 9.8 p. ct.	....
After heavy meal	248	302	1.46	[1]75	19.6
Increase with food	46 22.8 p. ct.	56 22.8 p. ct.	.27 22.7 p. ct.	14 23.0 p. ct.	....

[1]The pulse-rate was obtained in only one of the four periods after the light meal; in but two of the five periods after the heavy meal. (See table 8.)

One serious objection to this type of comparison, however, and an objection that measurably lessens the mathematical value of the increment due to food, is the fact that the periods after the midday meal followed the walking experiment in the morning, in which there was considerable muscular activity. As a matter of fact, the long-continued walking experiments, in which the walking was done at a rapid rate and the muscular activity was very severe, were not carried out until later in the spring of 1914, and hence in all probability we have not here to consider any great after-effect of the muscular activity of the morning which persisted throughout the experiment in the afternoon. Nevertheless, it is quite possible that at least a part of the excess metabolism after the midday or "heavy" meal may be explained by the fact that the subject had done considerable walking in the forenoon, while no such muscular activity preceded the after-breakfast experiments.

Of special significance here is the apparent striking relationship between the percentage increment in the total metabolism and the percentage increment in the pulse-rate. The increase in the heat-output after a light meal was 12 per cent and that in the pulse-rate 10 per cent, while after a heavy meal the increase in the heat output was 22.7 per cent and in the pulse-rate 23 per cent. This Laboratory has frequently emphasized in its publications the important relationship between the pulse-rate and the metabolism, the statements usually implying that an increase in the pulse-rate is simultaneous with an increase in the metabolism. Recently, in publishing the results of observations on a man who fasted 31 days,[1] it was pointed out in comparing the metabolism of the subject asleep and awake that the increment in the pulse-rate for the subject awake was directly proportional to the percentage increase in the metabolism. While it is by no means maintained that the increment in the pulse-rate for subject II was in direct proportion to the increase in the metabolism, it is of special interest to point out this second striking percentage relationship between the pulse increment and the metabolism increment, for such a quantitative relationship, if not partaking of the nature of a physiological law, at least serves to emphasize in a striking manner the importance of records of the pulse-rate in all metabolism experiments.

Occasion is here taken to note that a common error is found with writers who misapply the measurements of the pulse-rate in attempting to compare the pulse-rate of one person with that of another. Our experience in this Laboratory points to no relationship between the pulse-rate of two individuals, although the records for a single individual are frequently surprisingly proportional to the metabolism.

COMPARISON OF THE METABOLISM IN THE LYING AND SITTING POSITIONS.

Although observations were made of the metabolism of subject II in the post-absorptive condition for both the sitting and the lying positions, unfortunately the studies of the metabolism in the lying position were made some three weeks later than those of the metabolism in the sitting position, hence a comparison of the results is not free from criticism. If, however, we compare the average values found for the metabolism in the lying position on April 18, 1914 (see table 7), with the average of the values for the metabolism in the sitting position obtained on March 25 and 27 and April 3, 1914 (see table 8), we find a percentage increase in the carbon-dioxide output with the subject sitting over that with the subject in the lying position of 4.7 per cent, in the oxygen consumption of 7.4 per cent, in the heat production of 7.2 per cent, and in the pulse-rate of 7.0 per cent. According to these incomplete data, therefore, the increase in the metabolism with the subject sitting over that with the subject in the lying position is approximately 7 per cent.[2] We may also note here the agreement between the increment in the pulse-rate and that of the total metabolism.

---

[1]Benedict, Carnegie Inst. Wash. Pub. 203, 1915, p. 351.

[2]See, also, Emmes and Riche, Am. Journ. Physiol., 1911, **27**, p. 406.

METABOLISM IN VARIOUS STANDING POSITIONS.

With subject I no attempt was made to vary the character of the standing experiment, but with subject II numerous observations were made both with and without food and with the subject standing in various positions. A large majority of the experiments, *i. e.*, 53 experiments, were made when the subject was standing quietly in a relaxed position. Eight experiments were made with the subject standing in a relaxed position, but resting the hands upon a staff. Eight experiments were made with the subject leaning against a support, and finally 10 experiments were carried out with the man standing in the position of "attention." Since later we noted that there was considerable extraneous muscular activity incidental to walking at a rapid rate, which consisted for the most part of vigorous arm-motion, two experiments were made on May 11 and 15 in which the post-absorptive metabolism was measured with the subject standing still but moving his arms vigorously, simulating as nearly as possible the movement of the arms in rapid walking.

The results of the standing experiments with the subject in the post-absorptive condition will first be considered and are given in table 10. Since our interest is chiefly with the total heat-output, we may properly compare the metabolism in the various standing positions upon this basis.

When the subject stood in a relaxed position, his heat output varied from the very low value of 1.12 calories to 1.40 calories per minute, the average value being 1.25 calories per minute. When he stood in a relaxed position, but with his hands resting upon a staff, the average heat-output was essentially the same as in the first position, namely, 1.26 calories per minute; but when he leaned against a support there was a perceptible diminution in the heat-output, which then averaged but 1.18 calories per minute. It is, however, somewhat irregular to compare an average value for the relaxed position obtained from 26 experiments with the average values for other positions obtained from only 3 experiments; the slight changes in the metabolic level shown by these averages are therefore probably without significance. Essentially the same may be said of a comparison of the values obtained for the relaxed position with those obtained for the position of attention when the heat output increased only to 1.30 calories. Our general impression was that this subject did not maintain, to any great degree, a rigid position of "attention." From the foregoing comparison it is clear that the experimental evidence does not warrant the deduction that there is a measurable difference in the metabolism for any of the various standing positions in which the metabolism was studied, such as standing in a relaxed position, with the hands on a staff, with the subject leaning against a support, or standing in the position of "attention."

When instead of the muscular repose of these standing positions the subject swings his arms vigorously, as would be done in rapid walking, we note a great increase in the metabolism. Unfortunately there is not a particularly satisfactory agreement in the values obtained for the two experiments under these conditions, for on May 11 the heat-output per minute was 2.53 calories, or essentially 100 per cent greater than when the subject stood quietly, while on May 15 the metabolism was 3.13 calories or approximately 150 per cent greater than the metabolism of the subject when standing at rest.

TABLE 10.—*Metabolism of subject II standing in different positions in experiments without food.*
[Values per minute.]

Date.	Carbon dioxide.	Oxygen.	Heat-output (computed).	Pulse-rate.
1914				
Standing, relaxed:	*c.c.*	*c.c.*	*cals.*	
Mar. 20........	218	275	1.32	71
31........	209	260	1.25	71
Apr. 1........	213	266	1.28	75
6........	218	246	1.21	74
7........	214	257	1.24	82
	198	235	1.14	90
8........	204	265	1.26	..
9........	202	228	1.12	82
10........	212	257	1.24	78
14........	223	245	1.21	94
15........	214	252	1.23	74
16........	...	258	1.25[1]	90
17........	214	265	1.28	85
21........	205	242	1.18	78
22........	207	251	1.21	84
23........	208	252	1.22	74
24........	198	...	1.15	82
25........	192	264	1.24	79
27........	217	245	1.20	77
28........	221	274	1.32	82
May 5........	229	277	1.34	83
10........	215	246	1.20	74
11........	259	278	1.38	85
12........	226	293	1.40	82
13........	213	257	1.24	79
14........	209	257	1.24	80
Average......	214	258	1.25	80

Date.	Carbon dioxide.	Oxygen.	Heat-output (computed).	Pulse-rate.
1914				
Standing, staff:	*c.c.*	*c.c.*	*cals.*	
Mar. 24........	217	250	1.22	82
26........	223	253	1.24	80
Apr. 3........	224	278	1.34	77
Average......	221	260	1.26	80
Standing, support:				
Mar. 24........	196	256	1.22	79
26........	201	238	1.15	79
31........	214	239	1.17	77
Average......	204	244	1.18	78
Standing, attention:				
Mar. 25........	206	265	1.27	72
27........	219	272	1.31	71
31........	233	272	1.33	75
Average......	219	270	1.30	73
Standing, swinging arms:[2]				
May 11........	455	516	2.53	..
15........	554	643	3.13	..

[1]The average respiratory quotient of 0.83 is assumed in computing heat-output on this day.
[2]The subject stood swinging his hands and arms as vigorously as in the most rapid walking.

In the subsequent computations several basal values may be employed. The most obvious are those obtained with the subject in the lying position and, as has already been seen, we have the results of two series of measurements which were made with an interval of approximately two years. We have also used the value obtained with the subject in the standing position. With subject I, three periods with the subject standing almost invariably preceded the periods when the subject walked on the treadmill, but with subject II only one standing period preceded the walking periods. With subject II, therefore, instead of using the daily values found for the standing position, we have employed the average value found for the whole series of experiments, *i. e.*, 1.25 calories per minute. Special use will be made of the values found while the subject stood swinging his arms.

INFLUENCE OF FOOD UPON METABOLISM IN THE STANDING POSITION.

The experiments in which the subject was studied after the ingestion of food varied not only in the character of the food taken, but in the amount of food, the influence of both a light and a heavy meal being observed.

Influence of a Light Meal.

As we have seen from the data given in the historical summary table (table 1), it has been the custom of several investigators to make walking experiments after the subject had taken a moderate amount of food. We felt it important, therefore, to make observations under these conditions, since they would give information as to how long the

Table 11.—*Metabolism of subject II standing in different positions after a light meal.*

[Values per minute.]

Date.	Carbon dioxide.	Oxygen.	Heat-output (computed).	Pulse-rate.	Date.	Carbon dioxide.	Oxygen.	Heat-output (computed).	Pulse-rate.
1914					1914				
Standing, relaxed:	*c.c.*	*c.c.*	*cals.*		Standing, support:	*c.c.*	*c.c.*	*cals.*	
Mar. 16	{217	274	1.31	..	Mar. 28	{279	304	1.50	87
	{223	286	1.37	..		{246	276	1.36	81
18	224	293	1.42	..	Apr. 2	273	306	1.50	89
19	231	295	1.41	75					
21	271	338	1.62	98	Average	266	295	1.45	86
Apr. 2	253	281	1.38	86					
					Standing, attention:				
Average	240	295	1.42	..	Mar. 21	249	288	1.41	91
					30	261	271	1.35	76
					Apr. 2	248	268	1.33	78
Standing, staff:									
Mar. 23	282	333	1.62	74	Average	253	276	1.37	82
30	261	296	1.45	71					
Average	272	315	1.54	73	Average of all periods	253	294	1.43	82

ingestion of food influences metabolism when accompanied by muscular activity. With subject II the first meal of the day was usually a moderately light meal; accordingly on certain days he was permitted to eat breakfast before coming to the Laboratory for the experiments.

The results of the standing experiments after the morning meal are given in table 11. When the subject was standing in a relaxed position, the heat output averaged 1.42 calories per minute, this being an average value for 6 experiments. But two experiments were made with the subject standing with his hands resting on a staff, the average results being 1.54 calories, or somewhat higher than the average for the previous position. When standing in a relaxed position but leaning against a support, the subject had an average heat-output for three experiments of 1.45 calories per minute, while the same number of experiments with the subject in the position of "attention" gave an average heat-output of 1.37 calories. Obviously variations in the kinds and amounts of food must to a certain extent affect not only the individual values for the different days, but also the average values for the several groups; nevertheless the general statement made in considering the standing experiments with the subject in the post-absorptive condition, namely, that the metabolism was essentially the same for all of the four standing positions in which the metabolism was studied, also holds true here.

Averaging all of the values obtained in the standing experiments after the ingestion of a light meal, we find that the carbon dioxide per minute was 253 c.c., the oxygen consumption 294 c.c., and the heat-output 1.43 calories per minute. With the exception of the walking experiment on April 29, when a heavy carbohydrate breakfast was given as a control, the average value of 1.43 calories has been used as a basal value in calculating the increase in the heat-output during walking for all experiments after breakfast. For the walking experiment of April 29, the average basal value used for the computation of the increment due to walking was that obtained from the standing experiments of April 25 and 27 after a carbohydrate lunch had been taken (see table 12), this being the most logical value available for the purpose.

Influence of a Heavy Meal.

At noon subject II usually took a heavy meal and frequently returned to the Laboratory for a walking experiment in the afternoon. During April 1914 the character of the noon meal was controlled on several days. On 5 days he was given a meal of which the constituents were excessively high in protein; on 6 days the meal was particularly rich in carbohydrates; and on 4 days it was especially rich in fat. No attempt was made to control the amount eaten, although the statement was made that the "subject ate all that he could."

The values for all of the measurements made in the various standing positions after this noon meal are given in table 12. Comparing first the results obtained in the several standing positions and excluding the days with special diets, we find that the heat-output averages 1.56 calories when the subject stood in a relaxed position, 1.65 calories when he stood with the hands resting upon a staff, 1.47 calories when he leaned upon a support, and 1.52 calories when he stood in a position of "attention." All of these values were obtained after a heavy meal, with the diet uncontrolled. Recognizing again the probable influence of the preceding meal upon the individual values, we see, nevertheless, that the evidence points towards a practically constant metabolism independent of the variations in the standing position under approximately similar conditions.

Table 12.—*Metabolism of subject II standing in different positions after a heavy meal.*
[Values per minute.]

Date and conditions of experiments.	Carbon dioxide.	Oxygen.	Heat-output (computed).	Pulse-rate.
1914				
Diet uncontrolled:				
Standing, relaxed:	*c.c.*	*c.c.*	*cals.*	
Mar. 16	261	319	1.54	..
19	247	303	1.46	86
20	274	318	1.55	87
21	275	355	1.70	96
31	277	345	1.66	89
Apr. 1	283	319	1.57	86
3	244	293	1.42	81
Average	266	322	1.56	88
Standing, staff:				
Mar. 24	289	356	1.71	95
26	274	317	1.55	94
30	318	339	1.69	95
Average	294	337	1.65	95
Standing, support:				
Mar. 24	254	301	1.46	92
26	254	289	1.42	93
28	280	314	1.54	85
Average	263	301	1.47	90
Standing, attention:				
Mar. 21	270	295	1.46	94
25	292	309	1.54	95
27	294	298	1.50	95
31	265	326	1.57	89
Average	280	307	1.52	93
Average of all periods	274	317	1.55	91

Date and conditions of experiments.	Carbon dioxide.	Oxygen.	Heat-output (computed).	Pulse-rate.
1914				
Diet controlled:				
Standing, relaxed:				
Protein—	*c.c.*	*c.c.*	*cals.*	
Apr. 6	241	296	1.43	..
7	217	289	1.37	..
8	230	275	1.33	..
23	223	254	1.24	81
24	219	299	1.41	94
Average	226	283	1.36	88
Carbohydrate—				
Apr. 9	245	295	1.43	76
10	264	301	1.47	86
14	242	295	1.42	90
15	267	277	1.38	83
25	274	324	1.58	83
27	294	326	1.61	75
Average	264	303	1.48	82
Fat—				
Apr. 16	239	292	1.41	98
17	231	281	1.36	99
21	220	301	1.42	91
22	227	299	1.42	93
Average	229	293	1.40	95

During the observations made with the specially controlled diets, the subject stood in the relaxed position, without leaning upon a staff or against a support. These show an average value of 1.36 calories for the protein diet, 1.48 calories for the carbohydrate diet, and 1.40 calories for the fat diet, values not strikingly unlike those found on the days with an uncontrolled diet. We may then with propriety average the results obtained for the four groups of experiments in the relaxed position, *i. e.*, one group with an uncontrolled diet and three with controlled diets, and state that after the midday meal our subject showed with considerable constancy an average heat-output of 1.45 calories per minute.

From the values obtained in the experiments with the subject standing after a heavy meal, basal values were computed for use in calculating the increment due to walking under the same conditions of diet. Considering first the results obtained with an uncontrolled diet, we averaged the values determined with the subject standing in the four positions, *i. e.*, relaxed and unsupported, relaxed with the hands resting upon a staff, relaxed and leaning against a support, and the position of "attention." The averages found were 274 c.c. for the carbon-dioxide production, 317 c.c. for the oxygen consumption, and 1.55 calories for the heat-output. These averages were used for basal values in calculating the increase in the metabolism due to walking for all of the experiments following a heavy meal with an uncontrolled diet.

The average value found on the days with a diet rich in protein, namely, 1.36 calories, was used as a base-line for the walking experiments on May 5 and 10, as the standing metabolism was not determined on those days after the protein meal. A heavy protein meal was also taken on April 6, 7, 23, and 24, and both the standing metabolism and the metabolism during walking were determined. The standing values for the individual days were therefore used as the basal values for computing the increment due to walking.

The average value for the carbohydrate days was not used as a basal value for any of the walking experiments. For the walking experiments following the midday meal on May 4, 6, and 11, an average of the values obtained on April 25 and 27, *i. e.*, 1.59 calories, was used as a base-line in the computations, as the diets were considered to be more nearly comparable on those days. As has previously been stated, this basal value was also used for the walking experiment following the carbohydrate breakfast on April 29. For the experiments on April 9, 10, 14, 15, 25, and 27, the standing metabolism determined for that day was used as a basal value for the respective walking experiments which were subsequently made on that day.

On days when the diet was excessively rich in fat, the standing metabolism was always determined before the walking experiment and the values found were used as base-lines for the individual days, no use being made of the average value.

Conclusions Regarding Influence of Food upon the Standing Metabolism.

The average value for the metabolism in the standing experiments without food, as shown in table 10, was approximately 1.25 calories. After the light morning meal, the metabolism was 1.43 calories (see table 11) and after the heavy noon meal 1.45 calories. There was, therefore, an average increment of approximately 0.2 calorie or 16 per cent, due to the ingestion of the food. This value is strikingly in agreement with that found with subject I, and we may accordingly state that the basal metabolism of both subjects used in the research was increased approximately 16 per cent by the ingestion of the kinds and amounts of food consumed. This has an important bearing upon the subsequent calculations, for it is obviously impossible to make an intelligent comparison of the standing values obtained with individuals in the post-absorptive condition with those obtained after the ingestion of food.

Finally, it should not be forgotten that a part, at least, of the increment ascribed here to the ingestion of food, particularly after the noon meal, may be due to a slight after-effect of the muscular activity of walking in the forenoon experimental periods. On the other hand, there is such a close agreement between the increment in the metabolism after the light meal, which was invariably taken before the morning walking periods, and the increment in the metabolism after the midday meal, that it would imply that the influence of the morning work must have been extremely small.

METABOLISM DURING WALKING.

The preliminary study of the mechanics of position incidental to walking was obviously only for the purpose of throwing light upon the various mechanical processes involved in walking and the metabolism essential thereto. The primary purpose of the research was to study the actual metabolism during the motion of forward progression.

WALKING EXPERIMENTS WITH SUBJECT I.

The first series of walking experiments was made by Dr. Tigerstedt with subject I in the month of December 1913. These experiments were all carried out under practically the same conditions,—that is, following two or three periods when the subject stood in a relaxed position during which time the basal standing metabolism was measured. The body-weight of the subject was a practically constant factor, as it did not alter materially throughout the month. An attempt was made to maintain an essentially constant speed of the treadmill, the rate averaging not far from 76 meters per minute. In a few of the experiments, the speed was lowered to about 65 meters per minute, but in no instance did it exceed 80 meters per minute. Under these conditions we may consider that the study was based upon a constant speed and that accordingly all values are strictly comparable so far as the velocity is concerned. The walking experiments consisted of two or three and occasionally four periods per day. On two days walking experiments were made after the ingestion of food.

The results of all of the walking experiments with subject I are given in abstract in table 13. Inasmuch as the experience of previous investigators has shown that the variations in velocity play an important rôle in the total energy transformations, we have recorded here the distance per minute which the subject walked and have likewise computed the number of horizontal kilogrammeters by multiplying the distance per minute by the body-weight. From the kymograph records it was possible to find the average height to which the body was raised at each step by obtaining the average height of each recorded movement; by multiplying this average height by the number of steps, the total distance that the body was moved in a vertical direction could be computed with reasonable accuracy, thus giving a component for the analysis of the various factors involved in walking. The measurements of the distance that the body was elevated per minute are recorded in column *d*.

The total heat-output was calculated from the gaseous exchange not only for the walking periods but also for the standing periods preceding the walking; these values are recorded in column *e*. The increase due to walking was obtained by difference and the energy required to move 1 kilogram 1 meter in a forward direction, *i. e.*, 1 horizontal kilogrammeter, is recorded in gram-calories in column *g*. These latter values are obviously the most important result of this study.

EXPERIMENTS WITHOUT FOOD.

Considering first the values without food, it will be seen that the heat-output per horizontal kilogrammeter varies from a minimum of 0.446 gram-calorie to a maximum of 0.637 gram-calorie, but the large majority of the values lie close to the average value of 0.507 gram-calorie. A general inspection of these results shows indications of a periodicity or rhythm in the efficiency of this subject in walking. Thus, low values are found on December 2 and 3, which are followed by a group of high values continuing until December 22, while the last three experimental days that the subject was without food give distinctly lower values than those found in the preceding group. There is not, however, sufficient regularity in this rhythm to indicate the effect of training of the subject or in the use of the treadmill. To be sure, the first value, that of November 29, is considerably higher than the average and it is probably fair to assume that the high value of 0.637 gram-calorie found on December 15 was more or less accidental. On the other hand, we see no reason why these values should be rejected and the figures are sufficiently numerous to make it immaterial whether or not these or any other particular values are discarded so far as the influence upon the general average is concerned. While it may appear that the low values found on the last three days would imply the effect of training, it should be stated at the outset that this subject was a

TABLE 13.—*Increase in heat-output during walking in experiments with subject I.*
[Observations made by Dr. Carl Tigerstedt.]

Date and conditions of experiments.	(*a*) Body-weight with clothing.	(*b*) Distance per minute.	(*c*) Horizontal kilogrammeters. ($a \times b$).	(*d*) Raising of body per minute.[1]	Heat-output (computed). (*e*) Total per minute.	Increase over standing. (*f*) Total.	(*g*) Per horizontal kilogrammeter ($f \div c$).
1913 *Without food.*							
Nov. 29:	*kilos.*	*meters.*		*meters.*	*cals.*	*cals.*	*gm.-cal.*
Standing[2]...	.....	....	.....	....	1.35	....	....
Walking....	72.50	75.1	5,445	3.15	4.41	3.06	0.562
Dec. 1:							
Standing....	.....	....	.....	....	1.34	....	....
Walking....	72.60	76.0	5,518	3.26	4.10	2.76	.500
		76.6	5,561	3.36	4.35	3.01	.541
Dec. 2:							
Standing....	.....	....	.....	....	1.37	....	....
Walking....	73.12	76.2	5,572	3.20	4.03	2.66	.477
		76.8	5,616	4.62	4.10	2.73	.486
Dec. 3:							
Standing....	.....	....	.....	....	1.30	....	....
Walking....	72.80	76.5	5,569	3.57	4.07	2.77	.497
		77.2	5,620	3.62	4.07	2.77	.493
		77.5	5,642	3.68	4.19	2.89	.512
Dec. 4:							
Standing....	.....	....	.....	....	1.28	....	....
Walking....	73.01	77.7	5,673	3.41	4.19	2.91	.513
		77.7	5,673	3.68	4.22	2.94	.518
		78.2	5,709	3.57	4.14	2.86	.501
Dec. 5:[3]							
Standing....	.....	....	.....	....	1.57	....	....
Walking....	72.51	75.7	5,489	3.57	4.43	2.86	.521
		78.2	5,670	4.10	4.50	2.93	.517
		79.0	5,728	4.10	4.68	3.11	.543
Dec. 8:							
Standing....	.....	....	.....	....	1.29	....	....
Walking....	72.33	76.5	5,533	3.52	4.02	2.73	.493
		78.6	5,685	3.78	4.29	3.00	.528
		79.3	5,736	4.04	4.27	2.98	.520
		79.7	5,765	4.15	4.39	3.10	.538
Dec. 15:							
Standing....	.....	....	.....	....	1.32	....	....
Walking....	72.10	74.2	5,350	3.68	4.73	3.41	.637
		75.6	5,451	3.83	4.33	3.01	.552
		76.3	5,501	3.94	4.24	2.92	.531
		76.3	5,501	3.99	4.20	2.88	.524
Dec. 16:							
Standing....	.....	....	.....	....	1.37	....	....
Walking....	72.05	75.1	5,411	3.89	4.30	2.93	.541
		76.7	5,526	3.99	4.18	2.81	.509
		77.6	5,591	4.20	3.91	2.54	.454
Dec. 17:							
Standing....	.....	....	.....	....	1.31	....	....
Walking....	72.82	75.0	5,462	3.73	3.99	2.68	.491
		76.4	5,563	3.89	4.12	2.81	.505
		78.1	5,687	4.15	4.20	2.89	.508
		78.6	5,724	4.15	4.33	3.02	.528

[1]Computed from the average elevation of the body per step as obtained from the kymograph records and the steps per minute. See table 3 for information regarding number of steps.
[2]Usually three periods with the subject standing preceded the walking experiment.
[3]"No sleep but much alcohol" on the night preceding the experiment of Dec. 5.

TABLE 13.—*Increase in heat output during walking in experiments with subject I*—Continued.
[Observations made by Dr. Carl Tigerstedt.]

Date and conditions of experiments.	(*a*) Body-weight with clothing.	(*b*) Distance per minute.	(*c*) Horizontal kilogrammeters. (*a*×*b*).	(*d*) Raising of body per minute.[1]	Heat-output (computed). (*e*) Total per minute.	Heat-output (computed). Increase over standing. (*f*) Total.	Heat-output (computed). Increase over standing. (*g*) Per horizontal kilogrammeter. (*f*÷*c*).
1913 *Without food*—Continued.							
Dec. 18:	*kilos.*	*meters.*		*meters.*	*cals.*	*cals.*	*gm.-cal.*
Standing....	.....	....	.....	....	1.29	....	....
Walking....	74.76	75.3	5,629	3.52	3.98	2.69	.478
		76.4	5,712	3.68	4.09	2.80	.490
		76.7	5,734	3.68	4.19	2.90	.506
		76.9	5,749	3.73	4.22	2.93	.510
Dec. 19:							
Standing....	.....	....	.....	....	1.36	....	....
Walking....	74.17	76.1	5,644	3.83	4.29	2.93	.519
		77.9	5,778	3.99	4.23	2.87	.497
		78.3	5,808	4.10	4.26	2.90	.499
		78.7	5,837	4.20	4.26	2.90	.497
Dec. 20:							
Standing....	.....	....	.....	....	1.31	....	....
Walking....	74.31	76.2	5,662	3.68	4.00	2.69	.475
		77.7	5,774	4.04	4.28	2.97	.514
		78.6	5,841	4.20	4.43	3.12	.534
	—	78.9	5,863	4.25	4.48	3.17	.541
Dec. 22:							
Standing....	.....	....	.....	....	[2]1.34	....	....
Walking....	73.77	76.3	5,629	4.07	4.21	2.87	.510
		65.9	4,861	3.17	3.76	2.42	.498
		77.4	5,710	4.28	4.23	2.89	.506
		67.5	4,979	3.41	3.74	2.40	.482
Dec. 23:							
Standing....	.....	....	.....	....	[2]1.34	....	....
Walking....	73.75	75.9	5,598	3.97	4.03	2.69	.481
		66.4	4,897	3.07	3.55	2.21	.451
		76.9	5,671	4.08	4.14	2.80	.494
		66.4	4,897	3.30	3.66	2.32	.474
Dec. 27:							
Standing....	.....	....	.....	....	[2]1.34	....	....
Walking....	72.96	78.4	5,720	4.06	4.07	2.73	.477
		65.2	4,757	3.02	3.46	2.12	.446
		78.6	5,735	4.13	4.07	2.73	.476
		65.1	4,750	3.02	3.48	2.14	.451
Average...	73.10	75.9	.....	3.78	....	2.81	.507
With food.							
Nov. 26:							
Standing....	.....	....	.....	....	1.61	....	....
Walking....	73.30	75.3	5,519	3.57	5.03	3.42	.620
Dec. 9:							
Standing....	.....	....	.....	....	1.61	....	....
Walking....	72.33	76.0	5,497	3.68	4.61	3.00	.546
		78.3	5,663	3.89	4.39	2.78	.491
		79.1	5,721	4.04	4.33	2.72	.475

[1]Computed from the average elevation of the body per step as obtained from the kymograph records and the steps per minute. See table 3 for information regarding number of steps.
[2]Average of "standing" values obtained in experiments without food, Nov. 29–Dec. 20.

trained athlete, and although not particularly careful of himself, when out of training, he was nevertheless in reasonably good condition. The fact that alcoholic excesses preceded the experiment on December 5 shows, of itself, that the subject was not in strict training. Indeed, it was impossible for us to control him outside of the Laboratory.

In considering the values without food, it is of interest to note the variations in the standing metabolism in their relation to the total increase due to walking. While we find from the values given in table 6 that the average heat-output for this man without food was 1.34 calories per minute, it will be seen here that the variations ranged from 1.28 calories per minute on December 4 to 1.57 calories on December 5. The latter date was the day following the alcoholic excesses and it may be noted that this increase in the basal metabolism continued throughout the walking periods, as the three highest values for the heat-output during walking were found on this day. On the other hand, when the high basal metabolism is deducted, the gram-calories per horizontal kilogrammeter are essentially the same as the average value.

EXPERIMENTS WITH FOOD.

On the two days in which experiments were made with subject I after the ingestion of food, the standing or basal metabolism was perceptibly higher than in the experiments without food. The total metabolism during walking was likewise higher in all of the experimental periods. On the other hand, when the standing or basal metabolism is deducted, we find that the gram-calories per horizontal kilogrammeter were, in the second experiment, quite within the normal limits. We can find no explanation for the high value obtained on the first day. The fact that the high basal metabolism due to food persisted through the walking period is of special interest, as it shows that the muscular activity incidental to the amount and rate of walking in these experiments resulted in a metabolism which was superimposed upon the increased metabolism due to the ingestion of food. In general, we may say that when this subject walked on a level plane, the energy required over and above maintenance to move 1 kilogram over a distance of 1 meter, *i. e.*, 1 horizontal kilogrammeter, was in round numbers 0.5 gram-calorie. The correlation between these results and those obtained with subject II and the earlier observations of Benedict and Cathcart may properly be deferred until the discussion of the experiments with subject II.

ENERGY REQUIRED FOR THE ELEVATION OF THE BODY.

In walking at the average speed of 75.9 meters per minute, we find, from the records obtained with Dr. Tigerstedt's tracing pointer and by counting the number of steps, that the total distance per minute that the subject raised his body in a vertical direction amounted, on the average, to 3.78 meters per minute. With an average body-weight of

73.1 kilograms, this would correspond to a work equivalent of 276.32 kilogrammeters or 0.65 large calorie per minute. Since the total increase over the standing metabolism due to walking averaged 2.81 large calories per minute, it is seen that approximately 23 per cent of the energy required for the work of forward progression was employed in raising the body in a vertical direction.

These experiments give no data regarding the amount of energy required to lower the body after being raised at each step. Various assumptions are found for this in the literature, ranging from one-quarter to three-quarters of the work done in the elevation of the body, but it is obviously out of place to attempt such gross interpretations of the results.

In conclusion, then, we may say that when walking in a horizontal direction at the rate of 76 meters per minute, a man with a body-weight of 73 kilograms produces 2.81 calories per minute above his standing basal metabolism, of which 0.65 calorie or 23 per cent is required to raise the body through a distance of approximately 4 meters per minute. It is thus apparent at the outset that a very important factor in the energy consumption while walking in a horizontal direction may be the type of step employed. Unfortunately our observations were not made upon a sufficient number of persons to permit a complete discussion of this point.

WALKING EXPERIMENTS WITH SUBJECT II.

Subject II, who was a professional athlete, though not in continuous training, had exercised excessively in bicycle riding and had been the subject in Cathcart's research on the muscular work of bicycle riding. He had done a considerable amount of walking when in training, but was not an especially well-trained walker and certainly could not be classed as a professional pedestrian. On the other hand, he performed all of the tests on the treadmill at even the highest speeds with perfect ease and was at no time unduly distressed.

The walking experiments with this subject covered a period of approximately two months, *i. e.*, from March 16 to May 15, 1914. About 40 per cent of the experiments were made without food; the remainder of the experiments followed either the breakfast or the mid-day meal, the diet in some cases being controlled. The speed of rotation of the treadmill varied during the experiments without food from 56.0 meters per minute to 146.8 meters per minute and in a few experiments, with the subject running, it increased to 148.7 meters per minute. The greater part of the experiments were made with a speed between 56.0 and 93.3 meters per minute.

In computing the energy per horizontal kilogrammeter, we have the same problem to consider that was met with in the case of subject I, namely, the selection of a suitable base-line. As the tests with subject II were more varied than those with the first subject, at least three base-lines are possible, if not indeed permissible. These are, (1) the average resting value with the subject standing in a relaxed position, without support, which was obtained in 25 experimental days from March 20 to May 14, 1914, this value being 1.25 calories per minute; (2) the average resting, lying value of 51 experiments in 1911–12 by Benedict and Cathcart, this being 1.17 calories per minute, referred to here as lying value I; and (3) the resting lying basal value found as an average of four experimental periods on April 18, 1914, namely, 1.11 calories per minute, referred to here as lying value II. The subject in all these experiments was without food.

EXPERIMENTS WITHOUT FOOD.

All of the experiments without food for subject II have been brought together in table 14 and are arranged chronologically, the only disturbance in this order being for the experiment on May 13. The change in position for the experiment of May 13 was made to bring the results more nearly in the order of the increasing velocity of walking. The heat-output per horizontal kilogrammeter for each experiment has been computed in gram calories on the three base-lines previously cited. The results using a basal value obtained with the subject standing in a relaxed position are given in column *g;* those with an average basal value obtained by Benedict and Cathcart in their experiments between December 7, 1911, and April 16, 1912 (lying value I), are given in column *h;* and those with a basal value obtained from the special experiment made by Mr. L. E. Emmes on April 18, 1914 (lying value II), are given in column *i*. Inasmuch as the values for the subject standing relaxed were determined specifically for this research, and hence in this particular, at least, are more appropriate than the other basal values used, we shall lay great stress in our discussion upon the increments computed from this base-line.

A general inspection of the values in column *g* shows that there is a tendency towards constancy until May 4, at which time the rate of walking first exceeded 100 meters per minute. Considering the experiments when the speed was below 100 meters per minute, we find 57 periods with speeds ranging from 56 to 93.3 meters inclusive, the average speed being 71.5 meters per minute and the energy requirement for one horizontal kilogrammeter averaging 0.493 gram-calorie. An inspection of the table shows considerable variation above and below these average figures in isolated cases as, for instance, on April 15, when in one period the heat output per horizontal kilogrammeter was 0.603 gram-calorie. On the other hand the value of 0.555 gram-calorie is exceeded but six times and the individual values fall below 0.45 gram-calorie likewise only six times out of the 57 periods. It is thus clear that the value 0.493 gram-calorie is distinctly representative of the heat requirements for moving 1 kilogram 1 meter at speeds ranging from 56 to 93.3 meters per minute.

TABLE 14.—*Increase in heat-output during walking in experiments with subject II without food.*

Date and conditions of experiments.	(*a*) Body-weight with clothing.	(*b*) Distance per minute.	(*c*) Horizontal kilogram-meters (*a*×*b*).	(*d*) Raising of body per minute.	Heat-output (computed). (*e*) Total per minute.	(*f*) Increase above standing relaxed.	Increase per kilogram-meter (gram-calorie.) (*g*) Above standing relaxed (*f*÷*c*).	(*h*) Above lying, I.	(*i*) Above lying, II.
1914									
Standing, relaxed[1].....	*kilos.*	*meters.*	.....	*meters.*	*cals.* 1.25	*cals.*	*gm.-cal.*	*gm.-cal.*	*gm.-cal.* ....
Lying, I[2].....	....	....	.....	....	1.17	....	....	....	....
Lying, II[3]....	....	....	.....	....	1.11	....	....	....	....
Walking:									
Mar. 20..	72.4	(4)	.....	2.61	3.48	2.23	....	....	....
24..	72.0	60.6	4,363	1.09	3.74	2.49	0.571	0.589	0.603
25..	72.0	60.6	4,363	1.77	3.40	2.15	.493	.511	.525
26..	72.0	62.7	4,514	3.09	3.42	2.17	.481	.498	.512
27..	72.0	57.6	4,147	2.09	3.15	1.90	.458	.477	.492
31..	72.0	57.2	4,118	2.01	3.27	2.02	.491	.510	.525
Apr. 1..	72.0	59.3	4,269	2.22	3.36	2.11	.494	.513	.527
3..	72.0	76.2	5,486	2.38	4.39	3.14	.572	.587	.598
6..	72.0	57.8	4,161	1.78	3.32	2.07	.498	.517	.531
		56.8	4,090	1.83	3.25	2.00	.489	.509	.523
		56.0	4,032	1.91	3.20	1.95	.484	.503	.518
7..	72.0	59.6	4,291	1.98	3.53	2.28	.531	.550	.564
		58.2	4,190	1.95	3.19	1.94	.463	.482	.496
8..	72.0	76.1	5,479	3.01	4.45	3.20	.584	.599	.610
		77.6	5,587	2.81	3.97	2.72	.487	.501	.512
		78.3	5,637	2.85	3.89	2.64	.468	.483	.493
9..	72.0	59.3	4,269	1.92	3.40	2.15	.504	.522	.536
		58.8	4,233	2.05	3.20	1.95	.461	.480	.494
		59.0	4,248	1.98	3.36	2.11	.497	.516	.530
10..	72.0	77.3	5,566	2.77	4.09	2.84	.510	.525	.535
		78.9	5,681	3.21	4.09	2.84	.500	.514	.525
14..	71.9	61.7	4,436	2.45	3.43	2.18	.491	.509	.523
		62.1	4,465	2.34	3.28	2.03	.455	.473	.486
		62.4	4,487	2.37	3.26	2.01	.448	.466	.479
15..	71.5	77.2	5,520	3.33	4.58	3.33	.603	.618	.629
		79.4	5,677	3.52	4.02	2.77	.488	.502	.513
		80.2	5,734	3.49	4.04	2.79	.487	.501	.511
16..	71.5	61.9	4,426	2.38	3.16	1.91	.432	.450	.463
		62.3	4,454	2.37	3.22	1.97	.442	.460	.474
		61.8	4,419	2.20	3.21	1.96	.444	.462	.475
17..	71.5	76.6	5,477	3.36	4.36	3.11	.568	.582	.593
		78.1	5,584	3.45	3.94	2.69	.482	.496	.507
		79.3	5,670	3.80	4.14	2.89	.510	.524	.534
21..	70.5	60.8	4,287	2.32	3.13	1.88	.439	.457	.471
22..	70.5	76.8	5,415	3.33	3.91	2.66	.491	.506	.517
		78.6	5,542	3.44	3.97	2.72	.491	.505	.516
		79.2	5,584	3.42	3.94	2.69	.482	.496	.507
23..	70.5	61.1	4,308	2.53	3.27	2.02	.469	.487	.501
		(5)	.....	2.46	3.17	1.92	....	....	....

[1]Average of periods "standing, relaxed" as shown in table 10, p. 71.

[2]Average of results with this subject from Dec. 7, 1911 to Apr. 16, 1912. (See table 91, Benedict and Cathcart, Carnegie Inst. Wash. Pub. 187, 1913, p. 78.)

[3]Determined during four periods of an experiment on Apr. 18, 1914, the subject being without food.

[4]Probably at the rate of about 57 meters per minute.

[5]Probably at the rate of about 61 meters per minute.

TABLE 14—*Increase in heat-output during walking in experiments with subject II without food*—Continued.

Date and conditions of experiments.	(*a*) Body-weight with clothing.	(*b*) Distance per minute.	(*c*) Horizontal kilogram-meters (*a*×*b*).	(*d*) Raising of body per minute.	Heat-output (computed). (*e*) Total per minute.	(*f*) Increase above standing relaxed.	Increase per kilogrammeter (gram-calorie). (*g*) Above standing relaxed (*f*÷*c*).	(*h*) Above lying, I.	(*i*) Above lying, II.
1914 Walking—Continued;	*kilos.*	*meters.*		*meters.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cal.*	*gm.-cal.*
Apr. 24..	70.5	76.4	5,386	3.60	3.79	2.54	.472	.486	.498
		78.4	5,527	3.69	3.94	2.69	.487	.501	.512
25..	69.9	63.0	4,404	2.65	3.21	1.96	.445	.463	.477
		64.0	4,474	2.69	3.30	2.05	.458	.476	.489
27..	70.5	73.5	5,182	3.25	3.77	2.52	.486	.502	.513
		78.1	5,506	3.64	3.97	2.72	.494	.509	.519
28..	70.5	78.2	5,513	3.41	4.04	2.79	.506	.521	.531
		79.8	5,626	3.60	3.99	2.74	.487	.501	.512
		80.0	5,640	3.53	4.06	2.81	.498	.512	.523
		80.7	5,689	3.80	4.12	2.87	.504	.519	.529
		80.4	5,668	3.33	4.40	3.15	.556	.570	.580
		80.2	5,654	3.67	4.07	2.82	.499	.513	.524
		80.2	5,654	3.80	4.14	2.89	.511	.525	.536
		80.4	5,668	3.46	4.09	2.84	.501	.515	.526
May 13..	71.5	82.6	5,906	3.76	4.13	2.88	.488	.501	.511
		89.7	6,414	4.51	4.50	3.25	.507	.519	.529
		80.1	5,727	3.29	3.94	2.69	.470	.484	.494
		76.6	5,477	2.84	3.75	2.50	.456	.471	.482
		93.3	6,671	5.25	4.72	3.47	.520	.532	.541
		91.9	6,571	5.15	4.67	3.42	.520	.533	.542
4..	71.7	114.5	8,210	6.43	6.71	5.46	.665	.675	.682
		109.1	7,823	6.16	5.79	4.54	.580	.591	.598
		102.0	7,313	5.88	5.42	4.17	.570	.581	.589
5..	71.7	106.0	7,601	4.86	5.54	4.29	.564	.575	.583
		102.6	7,356	5.82	5.33	4.08	.555	.566	.574
		103.6	7,428	6.06	5.51	4.26	.574	.584	.592
6..	71.7	140.7	10,088	9.76	10.23	8.98	.890	.898	.904
		139.6	10,009	8.90	10.38	9.13	.912	.920	.926
		142.9	10,246	8.79	10.91	9.66	.943	.951	.956
10..	72.3	145.5	10,519	5.37	10.99	9.74	.926	.934	.939
		146.8	10,613	5.81	11.68	10.43	.983	.990	.996
		146.6	10,598	8.02	11.00	9.75	.920	.928	.933
Running:									
May 11..	72.0	146.6	10,554	13.45	9.47	8.22	.779	.786	.792
		146.7	10,562	13.89	9.57	8.32	.788	.795	.801
		148.3	10,677	14.80	9.69	8.44	.790	.798	.804
12..	72.0	147.1	10,591	15.40	10.80	9.55	.902	.909	.915
		148.4	10,684	14.09	9.19	7.94	.743	.751	.756
		148.1	10,663	15.40	9.80	8.55	.802	.809	.815
		148.1	10,663	14.74	9.97	8.72	.818	.825	.831
		148.7	10,706	15.37	10.06	8.81	.823	.830	.836
Walking:									
May 14..	71.5	146.4	10,467	7.59	11.23	9.98	.953	.961	.967
Running:									
May 14..	....	146.5	10,474	15.44	11.13	9.88	.943	.951	.957
		147.2	10,524	12.47	9.15	7.90	.751	.758	.764
		147.6	10,553	12.34	9.26	8.01	.759	.767	.772
		148.1	10,588	11.09	9.66	8.41	.794	.802	.808
15..	71.0	144.7	10,273	12.48	9.64	8.39	.817	.824	.830
		148.4	10,536	12.14	9.67	8.42	.799	.807	.812
		147.7	10,486	13.13	9.47	8.22	.784	.792	.797

In two of the walking experiments without food, those of April 6 and 7, we were able to obtain electrocardiograms of the pulse of this subject and the results are recorded in table 4 (pp. 54 and 55). In previous researches a striking uniformity has been found in the changes of the metabolism and the pulse-rate, amounting at times to a distinct percentage relationship between them. Such a uniformity was noted by Benedict and Cathcart in their study of a bicycle rider when the metabolism and pulse-rate during riding were compared with the values obtained in the lying or sitting position. In this research, on the contrary, the pulse-rate in the experiments of April 6 and 7 showed a distinct lowering when the subject changed from the standing position to walking, particularly in the experiment on April 7, notwithstanding the fact that the total metabolism during walking increased from 100 to 200 per cent above the basal metabolism of standing. This lowering of the pulse-rate was so positive that it is difficult to believe that any error was made in the measurements. Furthermore, in the fourth period of the experiment on April 7, we find that the pulse-rate with the subject standing after walking increased materially over that during walking. The evidence thus implies that when standing still upon the treadmill, this subject had a much higher pulse-rate than when he was walking at a slow speed. These records are entirely contrary to our previous experience but the lowered pulse-rate during walking has been confirmed by Professor H. Monmouth Smith, of the Laboratory staff, in similar experiments with three other subjects, thus establishing the fact. Further experimenting is now in progress and the results will be incorporated in a subsequent report.

Influence of Velocity.

On all days subsequent to May 4, with the single exception of May 13, the speed of walking exceeded 100 meters per minute. At this higher speed there was a distinctly higher energy requirement per horizontal kilogrammeter. Thus, we have six periods when the rate of walking was from 102 to 114.5 meters per minute and averaged 106.3 meters per minute. At this speed the average heat-output per horizontal kilogrammeter was 0.585 gram-calorie, a material increase over 0.493 gram-calorie, the average heat-output for the lower speed. A further grouping of the experiments is permissible when the speed ranged from 139.6 to 148.7 meters per minute, as with this higher speed a considerable increase is shown in the heat requirement per unit of work. Some of the experiments in this group show that when the subject ran instead of walked, the heat-output per horizontal kilogrammeter was lowered, although the rate of progression was practically the same; accordingly we may not advantageously draw average values. In the two walking experiments on May 6 and 10 the speed averaged 143.7 meters per minute and the heat per horizontal kilogrammeter 0.929 gram-calorie. In the first period of the experiment of May 14 the subject walked at the rate of 146.4 meters per minute, with a heat-output of 0.953 gram-calorie per horizontal kilogrammeter.

In the four following periods the subject ran, although the speed per minute was approximately the same as that in the walking period. Nevertheless, the average heat-output per unit of work was materially less, *i. e.*, 0.812 gram-calorie.

It is thus apparent that the velocity had a very considerable influence upon the heat per unit of work when the subject was walking. This confirms the earlier contention of Durig and his associates that the heat required to move 1 kilogram 1 meter increases with the speed. Furthermore, the method of progression, *i. e.*, walking or running, had likewise a very considerable influence on the heat per unit of work. Both of these factors require subsequent elaboration.

Comparison of the Heat per Unit of Work as Computed from Different Base-lines.

The last three columns of table 14 permit the comparison of the heat per unit of work, *i. e.*, per horizontal kilogrammeter, as computed from the three base-lines. Instead of using the individual values in table 14, however, this comparison can better be made by using only the average figures for the several groups presented in the foregoing discussion on the influence of velocity. To find exactly the differences due to the selection of the base-line, we have therefore brought together in table 15 a general average for all of the experiments without food, both walking and running. The walking experiments are divided into three groups, according to the speed at which the subject walked. Thus we have 57 periods when the subject walked at a slow rate ranging from 56 to 93.3 meters and averaging 71.5 meters, 6 periods with a medium speed averaging 106.3 meters per minute, and 7 periods with a high speed averaging 144.1 meters per minute. During the running experiments, the speed averaged 147.5 meters per minute. The values showing the heat-output per unit of work done, using the Benedict and Cathcart basal value (lying I), are given in column *b*, those for which the basal value of April 18, 1914, was employed (lying II) in column *c*, and those calculated from the basal value found with the subject standing in the relaxed position are given in column *d*.

With the large amounts of heat involved in the walking experiments the relatively slight differences appearing in these three base-lines should not have a very great effect. It is obvious, moreover, that the greater the amount of work done in walking, the less will be the percentage change due to the selection of the base-line. Thus we note that the heat per unit of work done at the slow speed is lower when the standing basal value is employed than it is when the lying value II (that of April 18, 1914) is used, the difference between the two averages being approximately 6 per cent. With the increase in the work involved in walking at the moderate speed, the difference due to the selection of the basal value becomes considerably less, *i. e.*, 3 per cent, and finally with the large heat production incidental to walking at the rate of 144.1 meters per minute, the difference between the calculations with the two base-lines becomes approximately only 1.5 per cent. This small difference likewise holds in the running experiments. The values computed from the Benedict and Cathcart base-line show the same general characteristics, although the difference between the two results is smaller than with the basal value of April 18, 1914.

It thus appears that as the total amount of work increases it becomes less important which of the three base-lines is used. For slow and moderate speeds a possible difference of 3 to 6 per cent in the average value of the heat per unit of work may be expected, while with the highest speed this difference decreases to from 1 to 1.5 per cent. The

TABLE 15.—*Comparison of heat-output during walking and running as referred to basal values for the lying and standing positions.*

[Experiments with subject II without food.]

Number of periods.	Average distance per minute (meters) (*a*)	Heat (computed) per horizontal kilogrammeter (gram-calorie).		
		Above lying I[1] (*b*)	Above lying II[1] (*c*)	Above standing relaxed[1] (*d*)
Walking:				
57.......	71.5	0.509	0.521	0.493
6.......	106.3	.595	.603	.585
7.......	144.1	.940	.946	.932
Running:				
15......	147.5	.814	.819	.806

[1]See table 14, p. 83, for explanation of basal values used.

importance of the selection of a basal value is therefore greatest when the amount of walking to be performed is smallest, *i. e.*, when the subject is walking at moderate speed. This is somewhat unfortunate, for a large proportion of walking for exercise, for the carrying of burdens, and in marching is usually done at a moderate speed. Since, however, the basal values obtained with the subject standing in the relaxed position were daily and accurately determined, and since there is such a high degree of constancy in the standing relaxed values, we consider that they may be properly used as the basal values for these computations. The figures obtained per unit of work on this basis may therefore be considered to represent the increased metabolism necessary to move 1 kilogram 1 meter in a horizontal direction.

EXPERIMENTS WITH FOOD.

A large number of experiments following the ingestion of food were made with subject II. The results of all these experiments are presented in table 16, the data being grouped arbitrarily according to the preceding meal and especially according to the character of the diet.

TABLE 16.—*Increase in heat-output during walking in experiments with subject II with food.*

Diet and date.	Condition.	(a) Body-weight with clothing.	(b) Distance per minute.	(c) Horizontal kilogram-meters (a×b).	(d) Raising of body per minute.	Heat-output (computed). (e) Total per minute.	Increase over standing. (f) Total.	(g) Per horizontal kilogram-meter (f÷c).
1914								
Breakfast.		*kilos.*	*meters.*		*meters.*	*cals.*	*cals.*	*gm.-cal.*
Not controlled:	Standing[1]..	....	....	.....	....	[1]1.43	....	....
Mar. 16..	Walking...	72.4	74.3	5,379	2.88	3.92	2.49	0.463
18..	....do.....	72.4	76.0	5,502	3.34	4.06	2.63	.478
		....	78.0	5,647	3.62	4.09	2.66	.471
19..	....do.....	72.4	74.9	5,423	3.16	4.21	2.78	.513
21..	....do.....	72.4	57.9	4,192	3.11	3.74	2.31	.551
23..	....do.....	72.4	57.9	4,192	2.74	3.40	1.97	.470
		....	57.5	4,163	2.61	3.74	2.31	.555
28..	....do.....	72.0	59.4	4,277	2.52	3.48	2.05	.479
30..	....do.....	72.0	58.5	4,212	2.26	3.65	2.22	.527
Apr. 4..	....do.....	72.0	55.1	3,967	1.91	3.23	1.80	.454
		....	56.8	4,090	1.98	3.07	1.64	.401
		....	56.2	4,046	1.87	3.24	1.81	.447
Controlled:								
Carbohydrate:								
Apr. 29..	Standing[2]..	....	....	.....	....	[2]1.59	....	....
	Walking...	70.9	76.9	5,452	3.63	4.31	2.72	.499
		....	78.2	5,544	3.56	4.26	2.67	.482
		....	79.5	5,637	3.52	4.20	2.61	.463
		....	80.9	5,736	3.74	4.07	2.48	.432
		....	81.1	5,750	3.76	4.09	2.50	.435
		....	80.9	5,736	3.29	3.87	2.28	.397
		....	81.0	5,743	3.73	4.10	2.51	.437
		....	81.1	5,750	3.69	3.98	2.39	.416
Lunch.								
Not controlled:	Standing[3]..	....	....	.....	....	[3]1.55	....	....
Mar. 16..	Walking...	72.4	75.3	5,452	3.17	3.99	2.44	.448
18..	....do.....	72.4	76.3	5,524	3.75	4.02	2.47	.447
19..	....do.....	72.4	74.9	5,423	3.55	4.09	2.54	.468
20..	....do.....	72.4	52.7	3,815	2.39	3.16	1.61	.422
21..	....do.....	72.4	52.8	3,823	2.59	3.40	1.85	.484
24..	....do.....	72.0	62.7	4,514	.81	3.99	2.44	.541
25..	....do.....	72.0	61.1	4,399	1.50	3.64	2.09	.475
26..	....do.....	72.0	60.7	4,370	2.30	3.67	2.12	.485
27..	....do.....	72.0	58.6	4,219	2.15	3.62	2.07	.491
28..	....do.....	72.0	59.3	4,270	2.12	3.81	2.26	.529
30..	....do.....	72.0	58.5	4,212	2.40	3.59	2.04	.484
		....	57.3	4,126	2.24	3.53	1.98	.480
31..	....do.....	72.0	57.7	4,154	1.72	3.53	1.98	.477
Apr. 3..	....do.....	72.0	57.0	4,104	2.02	3.44	1.89	.461
		....	77.0	5,544	2.84	4.68	3.13	.565
		....	78.9	5,681	3.38	4.47	2.92	.514
4..	....do.....	72.0	54.4	3,917	2.05	3.51	1.96	.500
		....	58.1	4,183	2.21	3.74	2.19	.524

[1]Average of all periods with subject standing after a light meal (breakfast). See table 11, p. 72.

[2]Standing, relaxed. Average of values obtained with similar diet on Apr. 25 and Apr. 27. See table 12, p. 74.

[3]Average of results obtained for all positions standing after lunch, diet not controlled. See table 12, p. 74.

TABLE 16.—*Increase in heat-output during walking in experiments with subject II with food*—Continued.

Diet and date.	Condition.	(*a*) Body-weight with clothing.	(*b*) Distance per minute.	(*c*) Horizontal kilogrammeters ($a \times b$).	(*d*) Raising of body per minute.	Heat-output (computed). (*e*) Total per minute.	Increase over standing. (*f*) Total.	(*g*) Per horizontal kilogrammeter ($f \div c$).
1914 *Lunch*—Cont'd. Controlled: Protein:		*kilos.*	*meters.*		*meters.*	*cals.*	*cals.*	*gm.-cal.*
Apr. 6..	Standing..	....	....	.....	....	1.43	....	....
	Walking...	72.0	57.5	4,140	2.21	3.54	2.11	.510
		....	57.2	4,118	1.94	3.51	2.08	.505
		....	56.3	4,054	1.81	3.46	2.03	.501
7..	Standing..	....	....	.....	....	1.37	....	....
	Walking...	72.0	58.8	4,234	1.78	3.59	2.22	.524
		....	58.7	4,226	1.83	3.77	2.40	.568
		....	56.9	4,097	1.82	3.41	2.04	.498
8..	Standing..	....	....	.....	....	1.33	....	....
	Walking...	72.0	76.9	5,536	2.50	4.28	2.95	.533
		....	78.0	5,616	3.01	4.38	3.05	.543
		....	79.2	5,702	2.70	4.46	3.13	.549
23..	Standing..	....	....	.....	....	1.24	....	....
	Walking...	70.5	61.2	4,315	2.74	3.55	2.31	.535
		....	61.6	4,343	2.57	3.44	2.20	.507
		....	61.6	4,343	2.48	3.45	2.21	.509
		....	61.7	4,350	2.63	3.45	2.21	.508
24..	Standing..	....	....	.....	....	1.41	....	....
	Walking...	70.5	77.0	5,428	3.74	4.05	2.64	.486
		....	78.8	5,555	3.88	4.11	2.70	.486
		....	80.0	5,640	3.84	4.26	2.85	.505
		....	80.0	5,640	3.88	4.24	2.83	.502
May 5..	Standing[1]..	....	....	.....	....	[1]1.36	....	....
	Walking...	71.7	112.6	8,073	7.69	6.34	4.98	.617
		....	113.7	8,152	7.83	6.43	5.07	.622
		....	106.0	7,600	6.40	5.89	4.53	.596
		....	111.3	7,980	7.76	6.31	4.95	.620
May 10..	Standing[1]..	....	....	.....	....	[1]1.36	....	....
	Walking...	72.3	146.5	10,592	7.83	11.05	9.69	.915
		....	146.9	10,621	8.28	11.07	9.71	.914
Carbohydrate:								
Apr. 9..	Standing..	....	....	.....	....	1.43	....	....
	Walking...	72.0	59.4	4,277	1.95	3.48	2.05	.479
		....	59.0	4,248	1.94	3.43	2.00	.471
		....	58.8	4,234	1.94	3.53	2.10	.496
Apr. 10..	Standing..	....	....	.....	....	1.47	....	....
	Walking...	72.0	78.0	5,616	3.01	4.70	3.23	.575
		....	79.1	5,695	3.17	4.59	3.12	.548
		....	79.7	5,738	3.35	4.37	2.90	.505
14..	Standing..	....	....	.....	....	1.42	....	....
	Walking...	71.9	61.2	4,400	2.38	3.40	1.98	.450
		....	62.0	4,458	2.20	3.54	2.12	.476
		....	62.2	4,472	2.27	3.47	2.05	.458
15..	Standing..	....	....	.....	....	1.38	....	....
	Walking...	71.5	78.2	5,591	3.88	4.52	3.14	.562
		....	80.1	5,727	3.72	4.41	3.03	.529
		....	80.6	5,763	3.88	4.63	3.25	.564

[1]Standing, relaxed; average obtained on 5 days with protein diet (table 12).

TABLE 16.—*Increase in heat-output during walking in experiments with subject II with food*—Continued.

Diet and date.	Condition.	(*a*) Body-weight with clothing.	(*b*) Distance per minute.	(*c*) Horizontal kilogram-meters ($a \times b$).	(*d*) Raising of body per minute.	Heat-output (computed). (*e*) Total per minute.	Increase over standing. (*f*) Total.	Increase over standing. (*g*) Per horizontal kilogram-meter ($f \div c$).
1914 *Lunch*—Cont'd. Carbohydrate—cont'd.		*kilos.*	*meters.*		*meters.*	*cals.*	*cals.*	*gm.-cal.*
Apr. 25..	Standing..	....	....	.....	....	1.58	....	....
	Walking...	69.9	63.1	4,411	2.88	3.52	1.94	.440
		....	63.8	4,460	2.70	3.53	1.95	.437
		....	63.7	4,453	2.85	3.49	1.91	.429
		....	63.3	4,425	2.64	3.34	1.76	.398
27..	Standing..	....	....	.....	....	1.61	....	....
	Walking...	70.5	77.5	5,464	3.60	4.30	2.69	.492
		....	78.9	5,562	3.56	4.02	2.41	.433
		....	79.8	5,626	3.88	4.24	2.63	.467
		....	80.2	5,654	3.74	4.04	2.43	.430
May 4..	Standing[1]..	....	....	.....	....	[1]1.59	....	....
	Walking...	71.7	113.4	8,131	6.84	6.59	5.00	.615
		....	112.3	8,052	7.88	6.46	4.87	.605
		....	110.3	7,909	7.41	6.10	4.51	.570
6..	Standing[1]..	....	....	.....	....	[1]1.59	....	....
	Walking...	71.7	143.0	10,253	7.82	10.73	9.14	.891
11..	Standing[1]..	....	....	.....	....	[1]1.59	....	....
	Running...	72.0	148.7	10,706	13.95	9.50	7.91	.739
Fat:								
Apr. 16..	Standing..	....	....	.....	....	1.41	....	....
	Walking...	71.5	61.6	4,405	2.49	3.35	1.94	.440
		....	62.3	4,455	2.48	3.15	1.74	.391
		....	62.2	4,447	2.24	3.43	2.02	.454
		....	61.9	4,426	2.21	3.42	2.01	.454
17..	Standing..	....	....	.....	....	1.36	....	....
	Walking...	71.5	77.6	5,548	3.96	4.06	2.70	.487
		....	79.5	5,684	3.78	4.27	2.91	.512
		....	80.0	5,720	3.85	4.56	3.20	.559
		....	80.0	5,720	3.67	4.15	2.79	.488
21..	Standing..	....	....	.....	....	1.42	....	....
	Walking...	70.5	60.4	4,258	2.45	3.33	1.91	.449
		....	60.6	4,272	2.56	3.43	2.01	.471
		....	60.5	4,265	2.34	3.44	2.02	.474
		....	60.5	4,265	2.23	3.43	2.01	.471
22..	Standing..	....	....	.....	....	1.42	....	....
	Walking...	70.5	77.3	5,450	3.86	4.07	2.65	.486
		....	78.7	5,548	3.86	4.24	2.82	.508
		....	79.5	5,604	3.92	4.25	2.83	.505
		....	79.7	5,619	3.84	4.18	2.76	.491

[1]Standing, relaxed. Average of values obtained with similar diet on Apr. 25 and Apr. 27. See table 12, p. 74.

As we have already seen from the discussion in an earlier section,[1] the metabolism in the standing relaxed position after the ingestion of food was considerably greater than that obtained when the subject was without food, this being due to the katabolic stimuli of the foodstuffs. Of most importance, however, is the question whether the increment due to walking is superimposed upon the increased katabolism due to food or whether this increment is lessened by the fact that the body is previously stimulated to a greater katabolic activity. With a view to studying the influence of variations in the intensity of the pre-walking stimulation, certain of the diets were so controlled as to consist in large part of one of the three principal food constituents, *i. e.*, protein, fat, or carbohydrate. With the experimental conditions and the impossibility of controlling the subject's diet while he was outside of the laboratory, it was impracticable to make a thorough study of this particular phase of the problem. Our data do not therefore present a conclusive statement as to the influence of the special protein, fat, or carbohydrate diets, but merely contribute to the interesting question as to whether or not the increase in the katabolism following the ingestion of food persists during increased muscular activity or if there be a summation effect under these conditions.

Since we have seen not only from the work of previous investigators, but from tables 14 and 15, that there is a marked influence upon the heat per unit of work as the result of an increase in velocity, particularly when the velocity is above 95 meters per minute, it seems preferable to consider the data presented in table 16 from this point of view. As in the experiments with this subject when no food was taken, here again we find that in the greater number of the experiments the speed varied from 52.7 to 81.1 meters per minute, there being but 7 periods at speeds ranging from 106 to 113.7 meters per minute, and but 4 periods with a speed over 140 meters per minute.

Considering first the experiments at the lower speed, we find that 91 periods are available for study. The average velocity during these periods was 68.2 meters per minute and the heat per unit of work done, *i. e.*, per horizontal kilogrammeter, was 0.486 gram-calorie. It will be seen from the table that the standing basal value for the total heat-output per minute in the experiments with food ranged from 1.24 to 1.61 calories per minute, averaging considerably above those obtained when the subject was standing in the post-absorptive condition. On the other hand, since the average value per unit of work done in 57 periods without food was 0.493 gram-calorie and the average of 91 periods with food was 0.486 gram-calorie, it is clear that the increase over the basal metabolism was the same in both instances; in other words, the increment due to the work of forward progression was

[1]See p. 75.

constant, irrespective of whether the subject was with or without food, this being true for subject II with the rate of speed varying from 52.7 to 93.3 meters per minute.

At moderate speeds above 100, we have seven periods with food in which the velocity varied from 106 to 113.7 meters per minute, the average speed being 111.4 meters per minute, and the average output of heat per unit of work done 0.606 gram-calorie. Certain difficulties appear when an attempt is made to compare the results of these periods with food with periods without food. First, the speed per minute without food was 106.3 meters and that with food 111.4 meters, this being a perceptible increase. Second, but few periods are available for comparison either with or without food, there being but 7 for the former and 6 for the latter. If we make such a comparison, however, we find that with food the heat per unit of work is 0.606 gram-calorie, while that without food was only 0.585 gram-calorie. It is probably not possible to attribute this increase in the heat-output per unit of work solely to the increase of 5 per cent in the speed, and we can only state that with speeds averaging 111.4 meters per minute the increase in the heat per horizontal kilogrammeter with food is perceptibly greater than that with food at a speed of 68.2 meters per minute.

The comparison becomes even more difficult when we consider the experiments with the highest speeds, namely, those of 140 meters per minute and over. Here we have but 4 periods with food, with the speed ranging from 143 to 148.7 meters per minute and an average speed of 146.3 meters per minute. The comparison is still further complicated by the fact that in one of these four periods the subject was running. The average heat-output per unit of work done for the three walking periods was 0.907 gram-calorie and the value found for the one period with the subject running was 0.739 gram-calorie, a value much less than that obtained with the subject walking.

We may thus say that all of the observations made after the taking of food are completely in accord with those made when no food was taken, *i. e.*, an increase in the energy per unit of work done as the speed increased and a considerably less energy per unit of work done when the subject was running as compared with that when he was walking. An analysis of the processes of running and walking and the character of the steps is necessary to interpret these differences intelligently.[1]

Electrocardiograms of the pulse-rate were obtained in a few of the experiments following the ingestion of food, namely, those of April 4, 6, and 7.[2] These records show the same discrepancy between the pulse-rate and the metabolism as was found in the experiments without food.[3]

---

[1]See p. 98. [2]See table 4, pp. 54 and 55. [3]See p. 85.

INFLUENCE OF THE CHARACTER OF DIET ON THE HEAT-OUTPUT PER UNIT OF WORK.

While from the general observations of the metabolism with and without food the inference was properly drawn that there was no material increase in the heat-output per unit of work in the food periods, nevertheless certain of the experiments permit a more detailed examination of this point since a reasonably satisfactory grouping of the results may be made upon the basis of the character of the diet. The experimental plan as originally outlined called for a series of walking experiments at each of the three standard speeds with diets containing a preponderance of each of the three principal nutrients.

The average figures representing the heat per unit of work with the three diets and the three speeds are collected in table 17. In this table the average speed for the different groups is given, as the speed per minute, especially with the low speed, was not exactly the same for the three diets. Only the walking experiments are considered in this connection, none of the running experiments being included.

Table 17 —*Influence of character of diet on the heat-output per horizontal kilogrammeter during walking experiments with subject II.*

Character of diet.	Low speed.		Moderate speed.		High speed.	
	Meters.	Gm.-cal.	Meters.	Gm.-cal.	Meters.	Gm.-cal.
Carbohydrate......	73.2	0.471	112.0	0.597	143.0	0.891
Protein............	67.1	.516	110.9	.614	146.7	.915
Fat...............	70.1	.478	.....	....	.....	....

Aside from the generally increasing value of the heat per unit of work as the speed increases, which is clearly shown in table 17, we note, in comparing the values obtained with the different diets, a distinctly higher, although not striking, increase in the heat per unit of work with the protein diet as compared with the carbohydrate diet, this increase being approximately 9 per cent at the low speed and 3 per cent at the moderate and high speeds. With the fat diet the comparison was made only with the low speed, and we find that the heat-output per unit of work was essentially the same as that with the carbohydrate diet and measurably less than was obtained with the protein diet. The general impression derived from the comparison of all the experiments with subjects I and II was that the heat per unit of work was practically independent of the taking of food. It appears from the foregoing discussion, however, that this conclusion should be slightly modified when diets containing large quantities of protein are considered, for the data in table 17 indicate that with such a diet a slightly higher heat-output per unit of work may be expected.

INFLUENCE OF FATIGUE UPON THE HEAT-OUTPUT PER UNIT OF WORK.

Many of our experiments were made with a sufficient number of consecutive walking periods to permit a study of the heat per unit of work done under conditions of accumulated work. The average length of the walking period was 14 minutes. The distance traveled in a period in the prolonged walking experiments varied from 800 to 1,200 meters, and the subject walked not only during the experimental periods, when the gaseous metabolism was being measured, but also between these periods. When, therefore, the experiment consisted of four or more experimental periods, it will be seen that the continuous walking would amount frequently to several kilometers, thus providing conditions for studying the effect of fatigue. In relatively few of these experiments, however, was there substantial evidence of extreme fatigue.

The results of the observations in which there were four or more periods of continuous walking are brought together in table 18. The data given show the total distance walked by the subject prior to the beginning of each experimental period[1] and both the distance walked per minute and the heat-output per unit of work performed during the period. On two days, April 28 and 29, 1914, there were eight walking periods; the total distance traversed each day in continuous walking was approximately 23 kilometers. Throughout both experiments the distance per minute remained essentially constant at about 80 meters; we thus have ideal conditions for studying the influence of fatigue resulting from continuous walking. On April 28, when the subject was without food, there was no essential difference in the unit of work done as the experiment progressed, although there were variations from period to period. On the next day, a similar experiment was made after food had been taken. The average heat per unit of work done on this day was considerably less than that on April 28 and a general tendency was also shown for the heat per unit of work done to decrease as the work progressed. Inspection of the values found for another experiment of 6 periods on May 13, when the subject was without food, shows more or less fluctuation in the values obtained for the heat per unit of work done, but there is no uniformity in the changes and, indeed, the values are somewhat greater in the last periods than in the earlier periods. With the experiments having only four periods, in which the total distance walked prior to the last period ranged from 8 to 12 kilometers, we find that on certain days there was a tendency for the heat per unit of work to decrease as the walking progressed and on other days to increase, but in the majority of the experiments there was no regularity in the variations.

From the data given in table 18, we may conclude that there may be noticeable differences in the absolute heat per unit of work done on different days, a point particularly brought out in the experiments of

---

[1]For total distance walked, see table 4, pp. 56 to 60.

April 28 and April 29. Nevertheless, there is no definitely uniform influence of prolonged walking upon the efficiency for horizontal movement shown by this subject and the heat per unit of work after he had walked 20 kilometers is as liable to be lower than the initial value as it is to be higher. In other words, in this series of experiments, the measured metabolism agrees perfectly with the subjective impression that there was not a sufficient degree of fatigue to affect the comfort

TABLE 18.—*Heat-output per unit of work during prolonged walking in experiments with subject II.*

Date.	Distance walked.		Heat (computed) per horizontal kilogram-meter.[2]	Date.	Distance walked.		Heat (computed) per horizontal kilogram-meter.[2]
	Total to beginning of period.[1]	Per minute during period.			Total to beginning of period.[1]	Per minute during period.	
1914				1914			
Without food:	*meters.*	*meters.*	*gm.-cal.*	With food:	*meters.*	*meters.*	*gm.-cal.*
Apr. 28...	382	78.2	0.506	Apr. 29..	650	76.9	0.499
	3,322	79.8	.487		3,519	78.2	.482
	6,316	80.0	.498		6,585	79.5	.463
	9,538	80.7	.504		9,699	80.9	.432
	13,062	80.4	.556		12,615	81.1	.435
	16,416	80.2	.499		15,547	80.9	.397
	19,033	80.2	.511		18,662	81.0	.437
	22,479	80.4	.501		21,676	81.1	.416
May 13...	521	82.6	.488	Apr. 22..	368	77.3	.486
	3,993	89.7	.507		3,452	78.7	.508
	7,737	80.1	.470		7,067	79.5	.505
	11,391	76.6	.456		10,345	79.7	.491
	16,413	93.3	.520	Apr. 23..	348	61.2	.535
	20,527	91.9	.520		2,723	61.6	.507
With food:					5,512	61.6	.509
Apr. 16...	303	61.6	.440		7,976	61.7	.508
	2,557	62.3	.391	Apr. 24..	354	77.0	.486
	5,901	62.2	.454		2,879	78.8	.486
	9,424	61.9	.454		5,541	80.0	.505
Apr. 17...	507	77.6	.487		8,295	80.0	.502
	3,945	79.5	.512	Apr. 25..	323	63.1	.440
	7,572	80.0	.559		2,330	63.8	.437
	12,266	80.0	.488		5,122	63.7	.429
Apr. 21...	307	60.4	.449		8,125	63.3	.398
	2,658	60.6	.471	Apr. 27..	372	77.5	.492
	5,374	60.5	.474		2,905	78.9	.433
	8,515	60.5	.471		5,693	79.8	.467
					9,366	80.2	.430

[1]For total distance walked, see table 4, pp. 56 to 60.
[2]Calculated for each period from the increment above values obtained with the subject standing relaxed. See tables 14 and 16, pp. 83 and 88.

of the subject or his metabolism and that at the speed used throughout these tests, namely, 80 meters per minute, walking may be done for many kilometers without affecting the efficiency of the body for locomotion in a forward direction.

The stamina of the subject and his capacity for excessive work was severely tested in the earlier research on prolonged bicycle riding, in which it was demonstrated that this subject had ridden the equivalent of 100 miles over average roads on an empty stomach; but in this research it was impracticable to carry out prolonged endurance tests at high rates of speed. Indeed, at the highest speed, *i. e.*, 140 kilometers per minute, it is very certain that the subject would have run instead of walked, as distances as great as 20 or more kilometers are rarely covered rapidly by walking, but usually by running. On the other hand, a speed of 80 meters per minute represents an average rapidity of motion when long-distance walking is to be done and hence the values obtained at this speed have a much greater practical use than would values secured with the subject walking at a higher speed.

COMPARISON OF THE HEAT-OUTPUT PER UNIT OF WORK DURING RUNNING WITH THAT OBTAINED DURING WALKING.

The striking difference between the heat per unit of work observed when the subject was running and that obtained when he was walking has already been noted in table 15 (see p. 87), the figures showing that considerably less energy per unit of work was required for moving the body forward in running than in walking under the experimental conditions. The values obtained when the subject was moving forward at the rate of approximately 144 meters per minute give the only data for a direct comparison, no running experiments being made at the lower rates of walking. At this speed, the value computed for walking (using the standing basal value) is 0.932 gram-calorie and for running 0.806 gram-calorie. That these are not accidental figures is shown by the fact that the first value is the average of 7 reasonably agreeing periods and the second value is the average of 15 well agreeing periods; in other words, we deal here with a positive difference of approximately 15 per cent. It thus becomes important to analyze, if possible, the mechanical movements incidental to walking, and particularly rapid walking, to find the reason for this discrepancy.

Traveling at the speed of 144 meters per minute, the ordinary individual without load generally runs rather than walks. On the other hand, in transporting heavy material as, for example, military accouterments and trappings, running would be wholly impracticable and walking must be resorted to. It has been noted, especially in observations of professional walkers, that in rapid walking there is commonly very great extraneous arm movement, the arms being violently swung back and forth with each step. In the belief that this unusual extraneous muscular movement results in a large energy transformation which does not directly contribute to the forward progression, the study previously referred to was made in which the energy requirement of subject II was observed while he stood and swung his arms violently as in rapid walking. These values have already been discussed in connection with the standing resting values,[1] when it was

[1]See table 10 and p. 71.

found that in one experiment the heat-output per minute was 2.53 calories and in the other 3.13 calories per minute, or an average heat-output of 2.83 calories per minute as compared with 1.25 calories per minute, the average of the basal values obtained with the subject standing relaxed. It will therefore be seen that when the arms were swung violently, the metabolism was increased 126 per cent.

It is accordingly important for us to eliminate, if possible, the influence of this extraneous arm motion. To this end we have computed in table 19 the heat-output per unit of work during rapid walking, using

TABLE 19.—*Increase in heat-output during fast walking in experiments with subject II.*

[Basal value, standing swinging arms.[1]]

Date.	Body-weight with clothing.	Distance per minute.	Heat-output (computed).		
			Total per minute.	Increase due to walking.	
				Total.	Per horizontal kilogrammeter.
1914					
Without food:	*kilos.*	*meters.*	*cals.*	*cals.*	*gm.-cal.*
May 6....	71.7	140.7	10.23	7.40	0.734
	....	139.6	10.38	7.55	.754
	....	142.9	10.91	8.08	.789
10....	72.3	145.5	10.99	8.16	.776
	....	146.8	11.68	8.85	.834
	....	146.6	11.00	8.17	.771
14....	71.5	146.4	11.23	8.40	.803
Average......	....	.....	.....	....	.780
With food:					
Protein—					
May 10....	72.3	146.5	11.05	8.11	.766
	....	146.9	11.07	8.13	.765
Carbohydrate—					
May 6....	71.7	143.0	10.73	7.56	.737
Average......	....	.....	.....	....	.756

[1]The subject stood without food swinging his arms violently as in the most rapid walking. (See table 10, p. 71.) In computing the results for walking without food, the average value (2.83 cals.) is used; for walking with food the increment (2.83 − 1.25 = 1.58 cals.) due to swinging the arms is added to the value obtained for "standing, relaxed" with the respective diets.

2.83 calories as the base-line, *i. e.*, the average value found with the subject standing and swinging his arms violently. Under these conditions we find a marked depression in the heat-output per unit of work as compared with that computed with a base-line obtained with the subject standing in a relaxed position. In the experiments without food, this averaged with the high speeds, 0.932 gram-calorie,[1] but with the new basal value, it averages 0.780 gram-calorie. This value compares favorably with the value of 0.806 gram-calorie[1] found in the 15 periods with the subject running, being some 3 per cent less.

[1]See table 15, p. 87.

In the experiments with food there is likewise a great decrease in the heat production per unit of work when this new base-line is used. Averaging the result of one period of fast walking after food on May 6 and those of the two periods on May 10, we find that the heat per unit of work is 0.756 gram-calorie as compared with 0.907 gram-calorie,[1] which is the average heat-output per unit of work as computed with the basal value found with the subject standing relaxed. The average of 0.756 gram-calorie agrees very closely with the value of 0.739 gram-calorie found in the experiment of May 11, 1914, when the subject was running after the taking of food.[1]

It would thus appear that the apparent disadvantage in walking a given distance at a speed of approximately 144 meters per minute as compared with running is due to the type of walking commonly employed by professional pedestrians and used by subject II, the extraneous movements of the arm playing an important rôle.

ANALYSIS OF THE MECHANICS OF LOCOMOTION.

The experimental data obtained in this research permit the comparison of several important factors in the mechanics of locomotion as we have accurate records of the distance walked per minute, the number of steps per minute and the height to which the body was raised per minute. These values for the varying conditions of walking and running and with and without food appear in several of the preceding tables[2] and have been used as the basis for computing the values compared in table 20. In this table the average values are given for the height to which the body was raised both per minute and per step, the distance walked or run per minute, the number of steps per minute, and the length of the step. The comparisons are made for the values obtained with the subject walking at low, medium, and high rates of speed, and with the subject running, the rate of progression for the latter being approximately the same as in walking at high speed.

TABLE 20.—*Mechanics of locomotion in walking experiments with subject II.*

Speed.	(*a*) Average raising of body per minute.	(*b*) Average distance per minute.	(*c*) Average number of steps per minute.	(*d*) Length of step (*b*÷*c*).	(*e*) Raising of body per step (*a*÷*c*).
Walking:	*meters.*	*meters.*		*cm.*	*cm.*
Low	2.88	69.3	108.2	64.0	2.66
Medium	6.69	109.0	130.9	83.3	5.11
High	7.90	144.5	152.4	94.8	5.18
Running	13.76	147.6	181.9	81.1	7.56

[1]See table 16. [2]See tables 4, 13, 14, and 16.

At the low speed the subject walked 69.3 meters per minute, and took 108.2 steps per minute, the average length of the step being 64.0 cm. With an increase in speed we note an increase not only in the number of steps per minute, but likewise in the length of the step, the number of steps per minute for the fast walking being 152.4 and the length of the step 94.8 cm. When we consider the height to which the body was raised, we find that the average height per minute was greatly increased as the speed increased, that obtained at the medium rate being more than twice the value secured with the low speed, *i. e.*, an increase from 2.88 meters to 6.69 meters. When the average values obtained at the medium and fast speeds are compared, we find that although the average distance walked per minute increased from 109.0 meters to 144.5 meters and the number of steps taken per minute from 130.9 to 152.4, the increment in the distance over which the body was raised was but 1.21 meters.

Of special interest in this connection is the extraordinary influence of the change in locomotion from fast walking to running. The increase in the speed was inconsiderable, being but 3.1 meters per minute. We find, however, that in running the average height to which the body was lifted increased from 7.90 meters to 13.76 meters per minute and the average number of steps from 152.4 to 181.9 per minute, the latter increment not being at all in proportion to the former. On the other hand, the length of the step was decreased in running from 94.8 cm. to 81.1 cm. It is thus apparent that in running the steps were taken much more rapidly and considerably shortened and that the body was raised to a much higher point at each step.

In any analysis of the mechanics of forward progression, therefore, we should bear in mind the fact that in running the body is actually lifted to nearly twice the height that it is raised during walking. This would of itself involve mechanical work not directly contributory to the work of forward progression and we should therefore expect to find, on this basis alone, that the work of walking would be much more economically done than the work of running. On the other hand, it has been pointed out in connection with the fast walking experiments that the subjects involuntarily, or possibly as the result of previous training, did an excessive amount of muscular work with the arms which likewise was not contributory to the motion of forward progression. If, however, in comparing the values for the heat output per unit of work done in walking and running, we use as a base-line the value obtained with the subject standing and swinging his arms vigorously, we find that the advantage still lies with the walking rather than with the running. Thus, while the heat-output per unit of work with the subject running without food is 0.806 gram-calorie with the standing relaxed base-line, when we use the base-line obtained with the subject swinging his arms the value becomes 0.780 gram-calorie for the 7 periods without food and

0.756 gram-calorie for the three periods with food, with an average value of approximately 0.768 gram-calorie. While these experiments are relatively few in number, it is quite possible that the apparent lower value obtained for walking as compared with running, after deducting the standing active base-line, may be explained by the fact that the body is elevated nearly twice as much when running as when walking and that to cover the same distance about 20 per cent more steps were needed. In the motion of forward progression we have therefore to take into account, first, the extraneous muscular activities not directly contributory to the work of forward progression, chief among these being the extraneous muscular movements of the arms in rapid walking which require the expenditure of a considerable amount of energy. Second, the type of step or the gait plays an important rôle, since in raising the body work is performed, requiring an expenditure of energy. When the body is raised approximately 14 meters per minute during running, it may be readily computed that with a man weighing 70 kilograms, this would be equivalent to raising 980 kilograms one meter in one minute corresponding to over 2.2 large calories. Any type of locomotion, therefore, which minimizes the raising of the body is the most economical. As a natural outcome of the study it will be seen that it would be desirable for athletes and others interested in the work of forward progression to develop a gait which will eliminate these two apparently unnecessary and extraneous factors, each of which requires the expenditure of a considerable amount of energy which is not directly contributory to the motion of forward progression.

Nutrition Laboratory of the
Carnegie Institution of Washington.
Boston, Massachusetts, June 19, 1915.