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Original Articles.

NOMOGRAPHIC CHARTS FOR THE CALCULATION OF THE METABOLIC RATE BY THE GASOMETER METHOD.*

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CHOICE OF APPARATUS.

As a result of the greatly increased interest in the basal metabolic rate as an aid in diagnosis in thyroid disorders, the question of the selection of the best apparatus for the determination in clinical work naturally arises. That apparatus is preferable which will determine the metabolic rate with the minimum of work and with sufficient accuracy for diagnostic purposes. The general idea is prevalent that a "metabolic rate approximately accurate and sufficiently good for clinical work" can be obtained by the use of some simple, apparently automatic apparatus run by an untrained person. Unfortunately, no such apparatus at present exists and it is highly improbable that such can be devised, because in this laboratory test we are dealing with gases and not with visible, ponderable matter (in the popular sense), and in consequence every step in the technic must be carried out so that errors will not oc-

cur in the determination of the volume and composition of the expired air or of the amount of oxygen gas absorbed by the patient. For these reasons the apparatus must be accurate and the technician must be especially trained in the proper handling of gases. *We have pointed out many times that the basal metabolic rate will fall into great discredit and the entire question of variation in the rates in various diseases be utterly confused by careless and improper technic in their determination.*

There are only two types of apparatus, the accuracy of which has been sufficiently controlled up to the present time by scientific experimentation to justify their consideration for clinical work. These are the Benedict closed-circuit system, and the open-circuit system, known as the Tissot or the gasometer method. Either type of apparatus, when properly constructed and properly run, will give accurate results. For the reasons later enumerated, we have been using, for the last four years, the gasometer or open-circuit system, which has proved most satisfactory and equally adaptable in our main laboratory where, with the aid of several technicians, we are carrying out thirty-five tests daily, and in a small subsidiary laboratory with one technician, who is able to do five complete tests a day.

In response to repeated requests as to the reasons for our choice of apparatus for clinical work, we give below the various points which, after consideration, led us to adopt the gasometer or open-circuit system. On the other hand, we do not wish to imply that excellent results cannot be obtained by a properly con-

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structed and skillfully run closed-circuit apparatus; and we wish to reiterate that the determination of accurate basal metabolic rates is not so much a question of which of these two forms of apparatus is used as it is of careful painstaking attention to the details of technique peculiar to each type of apparatus. Further, we desire to emphasize that both forms require far more care and accuracy in manipulation than do the "clinical tests" of various kinds in general diagnostic use and that the clinician planning to undertake metabolic rate determinations must be resigned to the expense and trouble incident thereto. With these reservations, the reasons for selecting the gasometer method for our laboratory are, then, as follows:

1. With the gasometer method the patient always breathes fresh out-door air, while in the closed-circuit apparatus, to prevent re-breathing the expired air of previous patients, it is necessary to rinse the entire apparatus several times with room air; if this is not invariably and carefully done, not only is the liability to air-borne infection increased, but also the contained air becomes most disagreeable.

2. The danger of transmitting pulmonary infection is obviated in the gasometer method since the inspired air never passes over tubing through which the expired air has passed, and the parts that are in contact with the patient can be cleaned readily. We consider the possibility of respiratory infection a serious criticism of the closed-circuit system.

3. In the gasometer method either a mask or a mouthpiece with nose clip may be used. With the closed-circuit system Benedict does not advise the use of a mask. Those who had experience with the army gas mask realize the troops' dislike for the mouthpiece: many hours of practice and drill were necessary before most of the men learned to breathe with ease through the mouthpiece and, in fact, there were some who never could use it properly. Also, from the point of view of the technician, the mask is preferable, especially when patients with dirty and infected mouths must be dealt with. Moreover, patients almost invariably express a very decided preference for the mask.

4. The loss of a given volume of air during an experiment with the gasometer method causes an error about one-twentieth as great as the loss of a similar volume from a closed-circuit system. This is a vital consideration since we have found that by far the most frequent cause of experimental error is a leak between the patient and the apparatus; we estimate that an error of appreciable magnitude occurs from this source in about 1 per cent. of our routine tests and is practically the only laboratory error that cannot be consistently avoided. In a closed-circuit system, any leak affects directly the oxygen reading, while with the gasometer method it means only the error caused by the loss of the 5 per cent.

oxygen that had been absorbed out of the air that was lost. Thus a leak of 100 cc. of the expired air during a ten-minute period with the gasometer method would cause an error of only 5 cc. in the calculation of the oxygen absorbed, or 0.5 cc. a minute, which is negligible. On the other hand, a leak of 100 cc. with the closed-circuit system would mean the loss of 100 cc. of oxygen, or 10 cc. per minute, an error which is not negligible. Errors of material magnitude in the estimation of the basal metabolic rate are therefore much more likely to occur frequently with the closed-circuit system than with the gasometer method.

5. Constant attention must be directed to keeping a closed-circuit system with its many connections absolutely air-tight, a procedure that involves many mechanical difficulties. On the other hand, with the gasometer, there are practically no mechanical difficulties, and therefore, it is particularly suitable for a girl to run.

6. The experimental period with the gasometer method can be started or ended without appreciable error at any phase of the respiratory cycle. In the closed-circuit system the experimental period must begin and end exactly at the bottom of a *normal* expiration; if this is not done with exactness, a large error results which can only be allowed for by a correction obtained from a kymographic record of the respiratory volume made for the entire experimental period.

7. A change in the character of the respiration during an experiment usually makes little or no difference with the gasometer method, while it materially affects the reading obtained by the closed-circuit system because of the inability to start and end the experiment with the same amount of air in the lungs. Also the swallowing of air or its eructation from the stomach may cause an error in a closed-circuit system.

8. The original difficulties from the burning out of the electric motor and the ignition or explosion of the oxygen-rich mixture have been decreased in the later models of the Benedict portable closed-circuit apparatus; however, the noise and vibration of the motor are annoying to many patients. The air pump is often of too small capacity and under conditions of actual use does not drive the air in sufficient volume through the soda lime to absorb completely the carbon dioxide. These difficulties are, of course, not present in the gasometer method.

9. The complete and rapid absorption of carbon dioxide by soda lime in the closed-circuit system is essential; otherwise, a serious error will result in the measurement of the oxygen absorbed by the patient and moreover, the unabsorbed carbon dioxide in the inspired air will cause a deepening of the respirations with a corresponding departure of the expiratory

base line from that obtained at the beginning of the experimental period. The direction of the first error due to the volume of the non-absorbed carbon dioxid by decreasing the apparent amount of oxygen absorbed tends to make the metabolic rate too low. The direction of the second error due to the increase in the respiratory volume caused by the effect of the accumulated carbon dioxid on the respiratory center tends to make the metabolic rate too high because a greater proportion of the air of the closed-circuit system will, at the end of an expiration, be in the lungs of the subject instead of in the measuring apparatus. Therefore, in many instances, these two opposing errors will balance each other and an approximately correct answer be determined accidentally; on the other hand, one error may be much larger than the other, depending on the exact manner in which the particular individual adjusts his respiratory mechanism to the increased carbon dioxid tension in the inspired air. Because a normal result is obtained on normal subjects does not necessarily mean that there are not fundamental errors in the use of the apparatus. These errors are often overlooked, because in the normals studied the two opposing errors happen to balance; furthermore, triplicate determinations obtained by using three inclusive time periods according to the method suggested by Emmes, may check and therefore the results are accepted as correct whereas, in fact, the two opposing errors only give a very rough approximation of the true determination. An advantage of the gasometer method with duplicate gas analysis is that no such balancing of errors is possible, and the technician is obviously warned that a mistake has occurred. In patients having hyperthyroidism, the carbon dioxid eliminated in a unit of time may be twice that of a normal person. Therefore soda-lime absorbers capable of taking care of the carbon dioxid as fast as eliminated by a normal person may not do so for a patient with an increased metabolic rate. Patients often complain of dyspnea as a result of incomplete carbon dioxid absorption, and are unable to continue the experiment more than five minutes.

It is often difficult to obtain good soda lime that is neither too coarse nor too fine and which has rapid carbon dioxid absorbing power. The preparation and filling of the soda lime bottles, which must be done frequently to avoid these errors is a dirty and time-consuming task.

10. For hospital work the gasometer method meets the requirement of portability since the apparatus can be wheeled to the patient's bedside.

11. The gasometer method lends itself readily to the use of duplicate readings, duplicate analyses, and mathematical checking.

12. The only advantage of the gasom-

eter method is the necessity for gas analyses. Furthermore, the analyses must be made in duplicate, and by a technician who thoroughly understands the use of a Haldane gas analysis apparatus. However, we have not found it difficult to teach high school graduates, in from four to eight weeks, to use a Haldane apparatus accurately; a trained laboratory worker can learn its use in one or two weeks. The principle of a Haldane is very simple, although it takes some time to acquire the manual dexterity necessary to use it properly. While we do not wish to minimize the difficulties of gas analysis, we believe that they have been magnified and do not outweigh the various advantages of the gasometer method just enumerated. For a detailed exposition of the technic of basal metabolic rate determinations by the gasometer method the reader is referred to the laboratory manual by Boothby and Sandiford.

ABRIDGED TABLES AND CALCULATION FORM.

Special detailed tables for the calculation of the metabolic rate by the gasometer method have been published by Boothby and Sandiford. However, for clinical work, their tables and method of calculation can be considerably condensed without appreciable loss in accuracy. Accordingly we are presenting abridged tables and a series of nomographic charts by which the metabolic rate can be calculated by a graphic method in less than five minutes. An abridged log factor table for reducing gas volumes to standard temperature and pressure dry is also included so that, if preferred, the calculation may be carried out first by logarithms and the result checked by the graphic charts. In our laboratory we prefer the combined method, since checking the results by a method entirely different from the original computation precludes the possibility of an error in calculation. For this purpose we have arranged a "calculation form" adapted for rapid checking of each step of the mathematical calculation by the charts. The condensed tables and calculation form are given at the end of this paper and are self-explanatory.

CONSTRUCTION OF THE NOMOGRAPHIC CHARTS.

There are many mathematical procedures for which it is possible to construct one or another form of nomographic chart to meet the needs of the various types of equations involved. The charts used in the calculation of the metabolic rate by the gasometer method of indirect calorimetry fortunately embrace four of the most common and most widely applicable equations. The method of construction of these charts is given in order to aid those who may desire to construct similar charts to solve a frequently used equation in their own work; in this description we shall follow closely the exposition of the subject given by Professor

Lipka in his book, "Graphical and Mechanical Computation," although we shall express ourselves in a less technical manner. The reader is referred to Lipka's excellent work for a complete mathematical exposition of the subject.

The simplest form of nomographic or alignment chart consists of a series of three parallel scales representing the component parts of an equation of three variables $f(u, v, w) = 0$. The scales are constructed in such a manner that a straight line (index line) cutting the three scales in values of u , v , and w satisfies the equation. In other words, the nomographic chart accomplishes the same purpose as a slide rule, only it solves the equation graphically.

In the construction of a chart its general plan must first be determined; this involves the consideration of the best form of equation to solve the problem, taken in conjunction with the size of the chart desired; the latter involves also the question of whether the chart is to be used in the original size or is to be reduced and on the accuracy or number of significant figures with which it is desired to express each function.

To obtain the desired length of the scale with the appropriate number of graduations, the proper modulus for each scale must be chosen. The scale modulus (designated by m) is that number of inches (or centimeters) which represents the length of the unit segment selected for the unit value of the variable to be plotted. The equation of the scale, $x = mf(u)$ is the equation by which the position of the different values of u on the scale is determined. For the calculation of a uniform scale where $f(u) = u$, the scale equation is $x = mu$ where m represents the length of unit division of the scale and as all the divisions are uniform, they may then be laid off by dividers.

In the case of a nonuniform or logarithmic scale, for example, when $f(u) = \log u$, the scale equation is $x = m \log u$ where m is the length selected to represent the entire logarithmic scale between 1 and 10; to construct a logarithmic scale all the main intermediate points must be determined by calculation or plotted by the use of a standard logarithmic scale.

The selection of the moduli to represent the unit lengths of the variables may be made arbitrarily for all but one of the variables of the equation to meet the requirements of the size of the chart and degree of accuracy (number of significant figures) desired; however, the modulus for the scale of the remaining variable of the equation is dependent on those already selected. For example, in an equation of three variables of the form $f_1(u) + f_2(v) = f_3(w)$ the moduli m_1 and m_2 are chosen arbitrarily, while m_3 is thereby fixed and determined by the formula $m_3 = \frac{m_1 m_2}{m_1 + m_2}$.

Likewise the distance between the u and v

scales may be selected arbitrarily; the position of the w scale between these two is thereby fixed and determined by the ratio of the moduli as follows: the distance between the u and v scales is to the distance between the w and v scales as m_1 is to m_2 . For example, if the distance between the u and v scales is selected as 10 inches and the modulus of the u scale is 10 and of the v scale is 20, then the distance of the w scale from the u scale is $10 \times 10/30 = 3.33$ and the distance of the w scale from the v scale is $10 \times 20/30 = 6.67$. Caution must be taken not to get the u and v scales too near together, which would give an uncertain and inaccurate intersection on the w scale. Judgment should be exercised in the choice of m_1 and m_2 because if m_1 is many times larger than m_2 , or *vice versa*, the w scale will have to be drawn too near the u or v scale. It is best to try to select the moduli so that the third scale may be erected not far from midway between the other two scales. If $m_1 = m_2$ then the w scale is erected exactly half way between the u and v scales.

A nomographic chart of three parallel scales solves equations of the general form $f_1(u) \pm f_2(v) = f_3(w)$, or $f_1(u) \times f_2(v) = f_3(w)$, or $f_1(u)/f_2(v) = f_3(w)$; these equations are similar because the two latter may be brought into the form of the first by taking logarithms of both sides of the equation. Of the equations involved in the calculation of the metabolic rate, three, namely: (1) $H^{0.725} \times W^{0.425} \times 0.007184 = S$; (2) $(C-N)/N = BMR$; and (3) $S \times C \times 24 = TC$, come under the form of this general equation and can, therefore, be solved by a three parallel line chart. In these equations H represents the standing height in centimeters; W , the weight in kilograms; S , the surface area in square meters; C , the basal calories per square meter per hour found experimentally; N , the normal basal calories per square meter per hour; BMR , the basal metabolic rate; and TC the total basal calories for 24 hours.

To construct a nomographic chart to solve the Du Bois formula for surface area: $H^{0.725} \times W^{0.425} \times 0.007184 = S$ take the logs of both sides of the equation: $0.725 \log H + 0.425 \log W + \log 0.007184 = \log S$, thus converting the equation into the first form of the general equations given above.

Arrange the data in tabular form (Table I) as follows: Under scale write the variables in the order given in the equation for the determination of the surface area; decide the limits within which the variables are to be used, which in this case are a height of 220 cm. and a weight of 200 kg. for the maximum and a height of 75 cm. and a weight of 15 kg. for the minimum; find the logs of the limits and subtract the two. In the next column are placed the moduli chosen for the various scales; if the length of the paper is chosen

TABLE I.

SCALE	LIMITS	LOG LIMITS	MODULUS*	SCALE EQUATION	LENGTH OF SCALE
f_1 (H)	220 cm. 75	2.3424 1.8751	$m_1=40''$	$x=m_1 f_1$ (H) $x=40 \times (0.725 \log H)$ $x=29 \log H$	$29 \times 0.4673=13.55''$
	difference	4.673			
f_2 (W)	200 kg. 15	2.3010 1.1761	$m_2=40''$	$y=m_2 f_2$ (W) $y=40 \times (0.425 \log W)$ $y=17 \log W$	$17 \times 1.1249=19.13''$
		1.1249			
f_3 (S)	3.00 sq. m. .50	10.4771—10 9.6990—10	$m_1 m_2$ $m_3 = \frac{m_1 m_2}{m_1 + m_2}$ $m_3 = \frac{40 \times 40}{40 + 40} = 20''$	$z=m_3 f_3$ (S) $z=20 \log S$	$20 \times 0.7781=15.56''$
		0.7781			

* In the construction of all the charts, the values of m given in the text are those which were employed originally in the construction of the scales; these figures do not refer to the charts as here reproduced since in all cases they are reductions of the original drawings.

as 24 inches we may select for trial 40 inches for m_1 ; then the equation of the H scale, $x = m_1 f_1$ (H) becomes $x = 40 \times 0.725 \log H$, or $x = 29 \log H$; if the range of log H is 0.4673 (the difference between log upper limit and log lower limit) the length of the scale will be $40 \times 0.725 \times 0.4673$, or 13.55 inches; the length of the scale so worked out is satisfactory for our purposes; otherwise a different modulus must be tried. Likewise, a suitable modulus must be chosen for the W scale. If 40 inches is again selected, and since the equation of the W scale is $y = m_2 f_2$ (W), then by substitution $y = 40 \times 0.425 \log W$ and its length is $40 \times 0.425 \times 1.1249 = 19.13$ inches. Since moduli m_1 and m_2 have been chosen, modulus m_3 is fixed by the formula $m_3 = (m_2 m_1) / (m_2 + m_1) = (40 \times 40) / (40 + 40) = 20$ inches. The distance between H and W scales is arbitrarily selected as 10 inches and the S scale is erected exactly half way between them because $m_1 = m_2$.

Having completed these preliminary calculations, the next step is to lay out these scales. First, find the middle point of the H scale by taking half the sum of the log limits: $(2.3424 + 1.8751) / 2 = 2.1088$, the antilog of which is 128.5 cm. Locate this point on the scale by a prick mark; determine where the point representing 125 cm. will be on the scale: this will be at a distance of $40 \times 0.725 (\log 128.5 - \log 125)$ inches below the central point 128.5, or $29 \times (2.1088 - 2.0969) = 0.35$ inches; locate and draw in the point representing 125 cm. on the H scale. Calculate the position of every 5 cm. variation in height above and below 125 until the limits 220 and 75 are reached. This can be done most efficiently by writing in a row all the logs of every 5 cm. above and below 125 and subtracting from each the log of 125 as follows:

180	185	140
2.1139	2.1303	2.1461
2.0969	2.0969	2.0969
0.0170	0.0334	0.0492

The resulting numbers, since the equation of the H scale is $x = 29 \log H$, are then multiplied on the slide rule by 29. For example: the point 130 will be at $29 \times 0.017 = 0.493$ inches above the point 125. The scale is then completed by dividing the intervening distances into equal parts. This is not strictly accurate, but it is sufficiently so when the distances between every fifth point are small, otherwise they should be calculated. This completes the H scale.

In like manner construct the W scale, except that the differences of the logs must be multiplied by 17 instead of 29, since the equation of the W scale is $y = 17 \log W$.

To determine a starting point for the graduations on the S scale, draw a straight line connecting two points on the H and W scales: for example, at 120 on H and at 50 on W. Solve mathematically this equation $S = 120^{0.725} \times 50^{0.425} \times 0.007184$, which is 1.219. Then the point where the line joining 120 on the H scale and 50 on the W scale crosses the S scale must be the point 1.219 sq. m. on the S, or the surface area scale. The point 1.200 on the S scale will be at a distance below 1.219 by $20 \times (\log 1.219 - \log 1.200) = 20 \times (0.0860 - 0.0792) = 0.136$ inches. Proceed as in the H scale and calculate the position of every 0.05 sq. m. surface area variation, multiplying the difference of logs by 20 since the equation of the S scale is $z = 20 \log S$. Draw in the scales, thus completing the chart.

The chart for the determination of the basal metabolic rate according to the formula $BMR = (C-N)/N$ is constructed in exactly the same manner as that for the surface area just described, since $(BMR + 1) \times N = C$ is in the form of the general equation $(u) \times (v) = w$, or $\log u + \log v = \log w$.

The chart for total basal calories per day, however, is somewhat more complicated in that it is a combination of the two preceding charts and contains five variables and solves the two formulae: (1) $H^{0.725} \times W^{0.425} \times 0.007184 = S$,

and (2) $S \times C \times 24 = TC$, or it may be expressed as one equation of the general form $f_1(u) + f_2(v) + f_3(w) + \dots = f_4(t)$ or $f_1(u) \cdot f_2(v) \cdot f_3(w) \cdot \dots = f_4(t)$ for four or more parallel scales. Since the chart is already drawn for the surface area as determined from the height and weight, we can use these same scales for the first half of the new chart for the determination of the total basal calories for twenty-four hours, providing we make use of the same modulus for the surface area (S) scale in the calculation of the additional scales. Proceeding as before, make Table II as follows:

TABLE II.

SCALE	LIMITS	LOG LIMITS	MODULUS	SCALE EQUATION	LENGTH OF SCALE
S	3.00	10.4771—10	$m_3 = 20$	$z = m_3 f_3(S)$	$20 \times 0.7781 = 15.56''$
	0.50	9.6990—10			
C		0.7781	$m_4 = 30$	$z = 20 \times \log S$	$30 \times 0.6021 = 18.06''$
	100	2.0000		$w = m_4 f_4(C)$	
	25	1.3979		$w = 30 \times \log C$	
TC		0.6021	$m_5 = \frac{m_3 m_4}{m_3 + m_4}$	$v = m_5 f_5(TC)$	$12 \times 1.1461 = 13.70''$
	7000	3.8451			
	500	2.6990			
		1.1461	$m_5 = \frac{20 \times 30}{20 + 30} = 12$	$v = 12 \times \log TC$	

The modulus ($m_3 = 20$) for S is fixed, because the surface area scale as obtained from height (H) and weight (W) is already drawn. By trial, a modulus (m_4) of 30 for the C scale is satisfactory, as it gives by the formula $m_5 = (m_3 m_4) / (m_3 + m_4) = (20 \times 30) / (20 + 30) = 12$ as the modulus (m_5) of the TC scale. These moduli are satisfactory because they give suitable scale lengths and at the same time allow a proper placing of the new scales in relation to the original scales. The TC scale is erected so that the ratio of the distance from the S

scale to the TC scale is to the distance from the TC scale to the C scale as 20 is to 30; since the distance between the S scale and the C scale may be satisfactorily placed at 8 inches, the distance of the TC scale from the S scale must be 3.2 inches. Proceed as described previously and find the center of the C scale and determine every fifth calorie. For convenience the Du Bois normal standards for men and women are also indicated along this scale. To work this chart, two index lines are necessary; the first joins the known height and weight, giving the surface area where it intersects the S line, and the second connects this latter point to the normal standard or C scale, giving, where it crosses the TC scale, the number of total basal calories per day for a normal person of known surface area.

Another type of chart known as the Z chart, is often very valuable for solving the general equations of the form $f_1(u) = f_2(v) \times f_3(w)$ or $f_1(u) = f_2(v) : f_3(w)$. The latter equation may be brought into the form of the first by taking the logs of both members of the equation as follows: $\log f_1(u) = \log f_2(v) + \log f_3(w)$. The first form of these equations is the same as the second form of the equation used in the construction of the preceding charts in which, however, three parallel logarithmic scales were used, while in the Z chart the scales are natural; two of the scales are parallel and uniform, while the third scale is not uniform and is laid out on a diagonal which connects the zero points of the other two scales, hence the name "Z chart." It can be used to solve the equations contraction in volume equals original volumes times per cent. of oxygen or carbon dioxide, or $D = E \times \%$, and the ratio between the carbon dioxide eliminated and the oxygen absorbed or $CO_2/O_2 = R.Q.$ The Z type of chart is of especial advantage in the first of these equations because the original volume and contraction in volume scales are uniform and may be constructed similar to those on the Haldane buret from which the readings are obtained. The parallel line type of chart, like those for Charts 1 and 2, could be used, but it would be less accurate and less easy to read in this instance, because the divisions would be constructed on a log scale and towards 10 would be small and difficult to interpolate.

In constructing the Z chart, select a convenient size of paper (20 inches by 30 inches) and lay out the two natural parallel scales any desired distance apart with the diagonal connecting the zero points of their scales. The natural scales then will run in opposite directions. According to the equation, $D = E \times \%$ make Table 3.

Lay off the D scale according to the scale equation $x = m_1(D)$, and the E scale according to the equation $y = m_2(E)$. By trial, we find that a modulus of 10 inches is suitable for both the contraction (D)

scale and original volume (E) scale. These scales may be laid off easily by means of an engineer's rule divided into tenths.

TABLE III.			LENGTH OF SCALE	
SCALE	LIMITS	MODULUS	SCALE EQUATION	
D	0 to 2.5	$m_1 = 10''$	$x = m_1 f_1(D)$ $x = 10 \times D$	$10 \times 2.5 = 25''$
E	7.5 to 10	$m_2 = 10''$	$y = m_2 f_2(E)$ $y = 10 \times E$	$10 \times 2.5 = 25''$
%	0 to 30	.....	$z = k \frac{m_1 f_1(\%) }{m_1 f_1(\%) + m_2}$ $z = 101.3 \frac{10 \times \% }{(10 \times \%) + 10}$	$101.3 \frac{10 \times 0.30}{(10 \times 0.30) + 10} = 23.4''$

Since the diagonal k connects the zero points of the two parallel scales, and since a suitable distance between the two parallel scales is 16 inches, and since for convenience in reading we have placed the point 10 on the original volume scale (E) exactly opposite the zero point on the contraction in volume scale (D), we have a right triangle and can easily calculate the diagonal k because it is the hypotenuse of a right triangle. For example, the complete length of the original volume scale 0 to 10 is 100 inches. Then the diagonal

$$k = \sqrt{100^2 + 16^2} = 101.3 \text{ inches}$$

The per cent. scale may be laid out on the diagonal according to the formula

$$z = k \frac{m_1 \% }{(m_1 \%) + m_2} \quad \text{or} \quad z = 101.3 \frac{10 \times \% }{(10 \times \%) + 10}$$

where z equals the distance from 0 to the positions on the diagonal representing the various values of the percentage scale.

Since the original volume is always between 7.5 and 10 that part of the chart from 0 to 7.5

is unnecessary and is therefore omitted. If this scale and the diagonal were prolonged, however, the latter would intersect the original volume scale at its zero point. Since only a segment of the chart is being constructed the diagonal must be laid off so that the tangent of the angle it makes with the contraction in volume scale is $16/100 = 4/25$. Therefore, to lay off this line measure 25 inches along the contraction in volume scale, starting from the zero point of that scale; measure four inches out perpendicular to the 25-inch point, and draw a line from the zero point of the contraction in volume scale through the end of the four-inch line; this will give a line laid off whose tangent to the contraction in volume scale is $16/100$. Since the per cent. scale is not uniform, it is necessary to calculate the location of every 0.5 per cent. by the scale formula; the 0.1 per cent. divisions may then be determined with sufficient accuracy by dividers. Complete the chart by drawing in the scales. The chart for the determination of the respiratory quotient is made in exactly the same manner as the preceding.

To work the chart a ruler is placed on the points representing the original volume and the contraction in volume, and the percentage is read off at the point where the ruler crosses the diagonal or per cent. scale.

In the preceding charts the equations have contained only three or five variables, and the charts are made so that the equation can be solved by means of one or two index lines. In the chart for the calories per square meter per hour, however, there are eight variables and one constant to deal with since:

$$C = \frac{Fg \times Cvo_2 \times Fstpd \times \% O_2 \times G \times 60}{M \times S}$$

and any chart which solves this equation must necessarily be more complex. In this equation C represents the basal calories per square meter per hour found experimentally; Fg , the factor for conversion of the linear rise in centimeters of the gasometer into volume in liters; Cvo_2 , the calorific value of oxygen for various respiratory quotients (R.Q.); $Fstpd$, the factor for reducing the observed gas volumes to standard temperature and pressure, dry; $\% O_2$, the per cent. of oxygen absorbed from the inspired air; G , the rise of the gasometer in centimeters; M , the duration of the test in minutes; S , the surface area in square meters and 60 converts the time from minutes to hours.

A combination of three superimposed rectangular charts was developed to solve this equation containing eight factors. A single rectangular chart consists of four natural scales arranged on each side and may be used to represent an equation of the form:

$$\frac{f_1(u) \cdot f_2(w)}{f_3(v) \cdot f_4(q)}$$

Three of the moduli may be chosen arbitrarily, but the fourth is fixed and solved from the equation,

$$\frac{m_1}{m_2} = \frac{m_3}{m_4} \text{ or } m_4 = \frac{m_2 m_3}{m_1}$$

A diagonal must connect the zero points of the four scales as in the z form of chart. The u and v scales must be laid off on opposite sides of the rectangle and the w and q scales on the other two sides with the 0 points of the u and w scales starting from the same point; similarly, the 0 points of the v and q scales must coincide at the opposite end of the diagonal. This diagonal, therefore, connects all four scales at their zero points. In the simple rectangular type of chart only four variables can be dealt with at one time; consequently the procedure was first to take three variables, G, C, and (60 x %O₂) and group all the other variables into one variable, X, and construct a chart; then take X with two of the other quantities 1/Fstpd and S and the remaining variables grouped as Y, and construct a second chart superimposed on the first; finally take Y with the remaining factors Fg, M and Cvo₂ and construct a third chart superimposed on the two preceding charts. The composite chart is solved by the use of six index lines; to facilitate its use a key indicating the order in which these index lines are to be made, is drawn in a convenient place on the chart. For the purpose of construction the original equation

$$C = \frac{Fg \times Cvo_2 \times Fstpd \times (60 \times \%O_2) \times G}{M \times S}$$

is expressed according to the form of the general equation in the three following equations:

$$(1) \frac{X}{(60 \times \%O_2)} = \frac{G}{C}$$

$$(2) \frac{X}{1} = \frac{S}{Y}$$

Fstpd

$$(3) \frac{M \times Cvo_2}{Fg \times Y} = \frac{M \times S}{Fstpd \times Cvo_2 \times Fg}$$

and Y represents $\frac{S \times C}{Fstpd \times G \times 60 \times \%O_2}$

By the proper choice of moduli it was found possible to obtain suitable scales for the various factors, and at the same time to prevent overlapping of the scales where more than two occurred on the same side of the chart. In order to distribute all the factors according to the form of the general equation,

$$\frac{f_1(u)}{f_2(v)} = \frac{f_3(w)}{f_4(q)}$$

it was found necessary to transfer by inversion, one of the factors Fstpd naturally occurring in the numerator to the denominator.

A size of paper four feet square was chosen for drafting. First, the quantities G, C and (60 x %O₂) are taken and all other quantities are grouped together under the variable X. It was found that the constant 60 could be taken care of best by using it with the per cent. of oxygen absorbed. If the modulus of X is taken for trial as 4.8, of (60 x %O₂) as 6, and of G as 0.4, the modulus of C must be $m_4 = 6 \times 0.4/4.8 = 0.5$, which is found suitable. The C scale will stretch from 0 to 37.5 inches; but the part of the scale from 0 to 15 need not be drawn. Similarly, in the other scales, only the part used need be actually marked off. The G, C and (60 x %O₂) scales with a diagonal connecting the zero point of the G scale with that of C and (60 x %O₂) scale can now be constructed. A second chart must be constructed superimposed on the first one, using the quantities Fstpd and S and grouping the remaining quantities under the variable X. Y must be used in this chart also so as to make this process continuous. In the second equation,

$$\frac{X}{1} = \frac{S}{Y}$$

Fstpd

the modulus for X (4.8) is already fixed from the preceding chart; by trial, the modulus of 10 inches for S and of 14.4 inches for 1/Fstpd is satisfactory. This latter scale, because of the form of the original equation, is an inverse instead of a uniform scale and therefore its divisions are not equal, and in consequence the position of its main points must be determined by calculation from the scale formula. The modulus for Y must therefore be $m_7 = 10 \times 14.4/4.8 = 30$. However, like X, the Y scale need not be graduated because it is a group of factors. From the form of this second equation the Fstpd (or rather 1/Fstpd) scale must be constructed opposite the Y scale and on the same line as the (60 x %O₂) scale and the X scale must be opposite the S scale, and the S scale adjacent to the Y scale and on the same line as the G scale.

The third and final equation is $M/Fg = Cvo_2/Y$. The modulus of Y is fixed from the previous equation and equal to 30. By trial the modulus m_{10} for $Cvo_2 = 50/6$ and the modulus m_8 for $Fg = 7.2$, are found suitable. Then the modulus m_8 for M is found by the equation,

$$m_8 = \frac{50}{6 \times 7.2} = 2$$

30

which is suitable, as it makes the minute scale a convenient length (30 inches). Complete the

TABLE IV.

	SCALE	LIMITS	MODULUS	SCALE EQUATION	LENGTH OF SCALE
(1)	$\frac{X}{60 \times \%O_2} = \frac{G}{C}$				
	X	.....	$m_1 = 4.8''$	.....	.....
	$60 \times \%O_2$	0 to 0.06	$m_2 = 6.0''$	$x_1 = m_2 f_2 (\%O_2)$ $x_1 = 6 \times 60 \times \%O_2$	$6 \times 60 \times 0.06 = 21.6''$
	G	0 to 90	$m_3 = 0.4''$	$y_1 = m_3 f_3 (G)$ $y_1 = 0.4 \times G$	$0.4 \times 90 = 36''$
	C	0 to 75	$m_4 = \frac{m_2 m_3}{m_1}$ $\frac{6.0 \times 0.4}{4.8}$ $m_4 = 0.5''$	$z = m_4 f_4 (C)$ $z = 0.5 \times C$	$0.5 \times 75 = 37.5''$
(2)	$\frac{X}{1} = \frac{S}{Y}$				
	Fstpd				
	X	.....	$m_1 = 4.8''$	.....	.....
	1	$\frac{1}{0.75}$ to $\frac{1}{1}$ or	$m_2 = 14.4''$	$y_2 = m_2 f_2 \left\{ \frac{1}{Fstpd} \right\}$	$14.4 \times 1.33 = 19.2''^*$
	Fstpd	1.33 to 1		$y_2 = 14.4 \times \frac{1}{Fstpd}$	$\frac{14.4}{Length} = 4.8''$
	S	0 to 2.6	$m_3 = 10''$	$x_2 = m_3 f_3 (S)$ $x_2 = 10 \times S$	$10 \times 2.6 = 26''$
	Y	.....	$m_4 = \frac{14.4 \times 10}{4.8} = 30''$	.....	.....
(3)	$\frac{M}{Fg} = \frac{Cvo_2}{Y}$				
	M	0 to 15	$\frac{50}{6} \times 7.2$ $m_5 = \frac{50}{30} = 2$	$z_3 = m_5 f_5 (M)$ $z_3 = 2 M$	$2 \times 15 = 30''$
	Fg	0 to 2.2	$m_6 = 7.2''$	$y_4 = m_6 f_6 (Fg)$ $y_4 = 7.2 \times Fg$	$7.2 \times 2.2 = 15.8''$
	Cvo ₂	0 to 5	$m_{10} = \frac{50''}{6}$	$x_4 = m_{10} f_{10} (Cvo_2)$ $\frac{50}{6} \times Cvo_2$	$\frac{50}{6} \times 5 = 41.8''$
	Y	.....	$m_7 = 30''$	.....	.....

* Note that the zero point of an inverted scale is infinity; therefore its divisions are not uniform and every point must be calculated.

chart by drawing in the various scales. To avoid looking up in a table the calorific value of oxygen for various respiratory quotients these values were charted in the corresponding terms of the respiratory quotient.

To read the chart one should follow the key, first arranging the data in the following order: minutes (m), factor of gasometer (Fg), respiratory quotient (Cvo₂), surface area (S), factor for reducing to standard temperature and pressure dry (Fstpd), oxygen per cent. (%O₂), and gasometer rise (G). Connect minutes with gasometer factor and locate the intersection on the diagonal with a sharp pencil or pin; next

connect this point with the respiratory quotient and find intersection on X axis; from this point draw a straight line to the surface area and again locate the intersection on the diagonal; connect this point with the surface area and find its intersection on the Y axis; then connect this point and oxygen per cent., and again note the intersection on the diagonal; connect this point and the gasometer reading, and where this line intersects the C axis read the answer in calories per square meter per hour.

The various scales are such that their limits cover the range of all except a few extreme

cases. With the exception of the scale for reducing the gas volume to standard temperature and pressure dry (Fstpd), the scales are constructed on the basis of uniform instead of logarithmic divisions so that interpolation can readily and accurately be made by dividers. The scale for reducing to standard temperature and pressure dry (Fstpd) is inverted and therefore not uniform, and so cannot be prolonged in an arithmetical ratio.

METHOD OF USING NOMOGRAPHIC CHARTS.

To use the charts accurately the following general precautions are necessary: The charts must be laid on a perfectly flat, smooth table, and must not be exposed to moisture. The ruler or straight edge to indicate the index line must be thin and true, and contain no irregularities. To prevent injury to the charts, it is best not to draw the various index lines but merely to indicate their positions by the straight edge of the ruler. By carrying out the following steps the position of the index line can be found most quickly: Locate the point on the right hand scale by means of a needle mounted in a handle; the latter can be improvised by sticking a needle through the rubber eraser of a lead pencil; bring the ruler's edge against the needle, which must be held perpendicular; with the little finger of the right hand, hold the ruler against the needle, which will serve as a pivot around which the ruler may rotate; swing the other end of the ruler over the left-hand scale position, being sure that the eye is perpendicular to this position, otherwise a considerable error will occur; hold the ruler firm with the left hand and place the needle exactly on the intersection of the ruler with the middle scale; if this is the answer, remove the ruler to facilitate reading of the scale; if further index lines are necessary, swing the left end of the ruler around the new needle position as pivot and establish the second index line by bringing the left end of the ruler directly over the new left scale position; the details of the maneuvers for each chart are given below.

Chart 1. Determination of the Carbon Dioxid and Oxygen Percentages.

In analyzing the expired air in the Haldane gas analysis apparatus, the various volumetric readings are made and the proper buret corrections added to them. The contraction in volume for carbon dioxid and oxygen is found by subtraction. To determine by the chart the carbon dioxid and oxygen percentages, place the needle upright on the right-hand scale over the original volume (9.426); bring the ruler close up against the needle and swing the edge of the other end of the ruler up to the contraction in volume for carbon dioxid (0.326) and read the answer (3.46%) on the per cent. scale; in like manner determine the oxygen per cent.

Chart 2. Determination of the Respiratory Quotient.

The respiratory quotient is the ratio between the carbon dioxid produced and the oxygen absorbed. The carbon dioxid produced is the difference between the per cent. of carbon dioxid in the expired (3.47%) and the per cent. in the inspired air (0.04%). The oxygen absorbed is the difference between the per cent. of oxygen in the expired air (16.62%) and the corrected inspired oxygen percentage (21.16%) obtained from Table 1 and corresponding to the sum of the carbon dioxid and oxygen per cent. of the expired air. To determine by the chart the respiratory quotient, place the needle on the right-hand scale position representing the per cent. of oxygen (4.54%) absorbed; bring the ruler against the needle and swing the left end to the exact position representing the per cent. of carbon dioxid (3.43%) produced; read the respiratory quotient, 0.76, on the middle scale.

Chart 3. Determination of the Surface Area (Du Bois).

In order to determine the surface area, place the needle on the scale representing the weight of the subject (53.1 kg); bring the ruler against the needle and swing its other end exactly over the height of the subject (155 cm.) and read the answer (1.50 sq. m.) on the middle scale.

Chart 4. Determination of the Calories Per Square Meter Per Hour.

The principle of Chart 4 is exactly the same as in the preceding charts except that as the chart solves an equation of eight factors and one constant, six index lines are necessary. An example for working the chart with the factors arranged in the order in which they are used, is as follows: Duration of experimental period in minutes: $M = 9.00$; gasometer factor for converting the linear rise of the gasometer to volume of expired air: $Fg = 1.26$; the calorific value of oxygen for the experimental respiratory quotient scaled on the chart as respiratory quotient: $Cvo_2 = 0.76$; the surface area of the subject: $S = 1.50$; the factor for reducing the gas volume read at experimental temperature of 22.8°C . and barometer of 728 mm. to standard temperature and pressure dry: $Fstpd = 0.854$; per cent. of oxygen absorbed: $\%O_2 = 4.54$; rise of the gasometer: $G = 56.7$. To solve the example, proceed according to the key on the chart: (1) Place the needle on $M = 9.00$; (2) swing the ruler exactly over $Fg = 1.26$; (3) place the needle on the diagonal exactly where the edge of the ruler crosses; (4) swing the ruler around the needle as a pivot to respiratory quotient (Cvo_2) = 0.76; (5) place the needle on the bottom line X exactly where the ruler crosses it; (6) swing the ruler around the needle as a pivot to $S = 1.50$;

CHARTS 1 AND 2

CHART FOR
BASAL METABOLIC RATE
DETERMINATIONS

CHART FOR BASAL METABOLIC RATE DETERMINATIONS

CO₂ AND O₂
PERCENTAGES
WM. BOOTHBY, R.B. SANDIFORD.
JANUARY 1921.

WM. BOUTWELL, JR. H.B. SANDIFORD, JR.
JANUARY 1921.

ORIGINAL

SURFACE AREA (5)

2.7 2.6 2.5 2.4 2.3 2.2
60 58 56 54

RESPIRATORY QUOTIENT (C_{vO_2})

9 88 86 84 82 80 78 76 74 72 70 68 66 64 62 60

ORIGINAL

GASOMETER (6)

Key

OXYGEN % ABSORBED (7Q)

PERCENT CARBON DIOXIDE

PERCENT

CALORIES PER SQUARE

W.M. BOOTHBY
PERCENTAGES
CO² AND O²
1921

DETERMINATIONS BASAL METABOLIC RATE CHART FOR

CHART 4

CHART FOR BASAL METABOLIC RATE DETERMINATIONS

CALORIES PER SQUARE METER PER HOUR
W.M. BOOTHBY. R.B. SANDIFORD.
SEPTEMBER 1920.

MINUTES (M)

PERCENTAGES

CALORIES PER SQUARE METER PER HOUR (C)
DETERMINATION IN LOGARITHM

CHART 3

BASAL METABOLIC RATE.

CHART 5

(7) place the needle exactly on the crossing of the diagonal; (8) swing the ruler to $F_{std} = 0.854$; (9) place the needle on the line Y exactly where the ruler crosses it; (10) swing the ruler to $\%O_2 = 4.54$; (11) place the needle on the crossing of the diagonal; (12) swing the ruler to $G = 56.7$; (13) read the answer in calories per square meter per hour, 58.4, on the bottom line where the ruler crosses the C. scale. This answer will agree if care has been taken within ± 0.2 calories of the result obtained by carrying out the calculation by four-place logarithms.

Should the total calories per hour be desired, instead of the calories per square meter per hour, procedure six is modified by using a surface area of 1.00 instead of the individual's surface area. As the gasometer factor is always the same for the same gasometer, the calculator can make a permanent mark for his own gasometer at the appropriate place on the Fg scale. As most experimental periods are of ten minutes' duration, the first and second maneuvers can be eliminated for those periods of exactly ten minutes by making a fine permanent intersection mark on the diagonal corresponding to the third maneuver. In case the gasometer factor does not fall within the range of the scale drawn on the chart, the appropriate point for any gasometer can be determined readily by extrapolation, and its position permanently marked on the chart. Similarly the oxygen per cent. scale can be prolonged to meet the needs of the occasional instances in which the per cent. absorbed is beyond the range of the scale; occasionally it is necessary to prolong the base line X for the sixth maneuver.

Chart 5. Determination of the Basal Metabolic Rate.

In order to determine the basal metabolic rate, place the needle on the scale for calories per square meter per hour (58.4) determined by Chart 4, and bring the left hand edge of the ruler to the appropriate normal standard on the left-hand scale (female, aged 30), and read the answer where the ruler crosses the right-hand scale ($+ 60$ per cent.).

Chart 6. Determination of the Basal Calories for Twenty-four Hours.

Charts 1 to 5 are for the determination of the basal metabolic rate. Chart 6, however, is for the calculation of the basal calories for twenty-four hours in order to determine readily the amount of food requisite for various individuals. It was constructed at the suggestion of Dr. R. M. Wilder of the Mayo Clinic for dietetic work. In determining the quantity of food required by an individual, it is more accurate to base the number of food calories on the four factors of age, sex, height and weight, according to Du Bois' standards, than on weight alone, as has been the general custom.

TABLES 1, 2, 3.

Correction Inspired Oxygen Percentage to Basis of Expired Volume.

CO ₂ + O ₂	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
19.5	21.32	21.32	21.31	21.31	21.31	21.31	21.30	21.30	21.30	21.30
19.6	21.29	21.29	21.29	21.28	21.28	21.28	21.28	21.27	21.27	21.27
19.7	21.27	21.26	21.26	21.26	21.26	21.25	21.25	21.25	21.25	21.24
19.8	21.24	21.24	21.24	21.23	21.23	21.23	21.22	21.22	21.22	21.22
19.9	21.21	21.21	21.21	21.21	21.20	21.20	21.20	21.20	21.19	21.19
20.0	21.19	21.18	21.18	21.18	21.18	21.17	21.17	21.17	21.17	21.16
20.1	21.16	21.16	21.16	21.15	21.15	21.15	21.15	21.14	21.14	21.14
20.2	21.13	21.13	21.13	21.13	21.12	21.12	21.12	21.12	21.11	21.11
20.3	21.11	21.10	21.10	21.10	21.10	21.09	21.09	21.09	21.09	21.08
20.4	21.08	21.08	21.08	21.07	21.07	21.07	21.07	21.06	21.06	21.06
20.5	21.05	21.05	21.05	21.05	21.04	21.04	21.04	21.04	21.03	21.03
20.6	21.03	21.03	21.02	21.02	21.02	21.02	21.01	21.01	21.01	21.00
20.7	21.00	21.00	21.00	20.99	20.99	20.99	20.99	20.98	20.98	20.98
20.8	20.98	20.97	20.97	20.97	20.96	20.96	20.96	20.96	20.95	20.95
20.9	20.95	20.95	20.94	20.94	20.94	20.94	20.93	20.93	20.93	20.93
21.0	20.92	20.92	20.92	20.91	20.91	20.91	20.91	20.90	20.90	20.90
21.1	20.90	20.89	20.89	20.89	20.89	20.88	20.88	20.88	20.87	20.87
21.2	20.87	20.87	20.86	20.86	20.86	20.86	20.85	20.85	20.85	20.85

Equivalent of Seconds in Decimal Parts of a Minute.

Sec.	Min.	Sec.	Min.	Sec.	Min.
1	0.02	21	0.35	41	0.68
2	.03	22	.37	42	.70
3	.05	23	.38	43	.72
4	.07	24	.40	44	.73
5	.08	25	.42	45	.75
6	.10	26	.43	46	.77
7	.12	27	.45	47	.78
8	.13	28	.47	48	.80
9	.15	29	.48	49	.82
10	.17	30	.50	50	.83
11	.18	31	.52	51	.85
12	.20	32	.53	52	.87
13	.22	33	.55	53	.88
14	.23	34	.57	54	.90
15	.25	35	.58	55	.92
16	.27	36	.60	56	.93
17	.28	37	.62	57	.95
18	.30	38	.63	58	.97
19	.32	39	.65	59	.98
20	.33	40	.67	60	1.00

Calorific Value of One Liter of Oxygen for Various (Non-Protein) Respiratory Quotients together with the Log of the Calorific Value to which is Added the Log of 60 min.

R.Q.	Cals.	Log	R.Q.	Cals.	Log
0.71	4.69	2.4494	0.86	4.88	2.4862
.72	4.70	4505	.87	4.89	4673
.73	4.71	4517	.88	4.90	4684
.74	4.73	4528	.89	4.91	4695
.75	4.74	4539	.90	4.92	4705
.76	4.75	4551	.91	4.94	4716
.77	4.76	4562	.92	4.95	4727
.78	4.78	4573	.93	4.96	4738
.79	4.79	4584	.94	4.97	4748
.80	4.80	4596	.95	4.99	4759
.81	4.81	4607	.96	5.00	4770
.82	4.83	4618	.97	5.01	4781
.83	4.84	4629	.98	5.02	4791
.84	4.85	4640	.99	5.03	4802
.85	4.86	4651	1.00	5.05	4813

TABLE 4.

Log Factor for Reducing Volume of Gases to Standard Temperature and Pressure, Dry; Including Reduction of Barometric Height to Standard Temperature (brass scale).

Barometer in Millimeters.																
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
700	1.9298	9277	9255	9233	9211	9188	9164	9141	9117	9093	9068	9044	9017	8991	8964	8937
702	9310	9289	9267	9245	9223	9200	9177	9153	9129	9105	9080	9056	9029	9003	8976	8949
704	9323	9302	9279	9257	9236	9212	9189	9166	9142	9118	9093	9069	9042	9016	8989	8962
706	9335	9314	9292	9270	9248	9225	9202	9179	9155	9131	9106	9082	9055	9029	9002	8975
708	9348	9327	9305	9283	9260	9237	9214	9192	9167	9143	9118	9094	9067	9041	9014	8987
710	9361	9340	9318	9296	9273	9251	9228	9205	9181	9157	9132	9108	9081	9055	9027	9001
712	9373	9352	9330	9308	9285	9263	9240	9217	9193	9169	9144	9120	9093	9067	9040	9015
714	9385	9364	9342	9320	9298	9275	9252	9229	9206	9181	9157	9133	9106	9080	9054	9027
716	9398	9377	9355	9333	9311	9288	9265	9242	9218	9194	9170	9146	9119	9093	9067	9040
718	9410	9389	9367	9345	9323	9300	9277	9254	9230	9206	9182	9158	9131	9105	9080	9052
720	9423	9402	9380	9358	9336	9313	9290	9267	9244	9220	9195	9171	9145	9119	9093	9066
722	9435	9414	9392	9370	9348	9325	9302	9279	9256	9232	9207	9183	9157	9131	9105	9078
724	9447	9426	9404	9382	9360	9337	9314	9291	9268	9244	9219	9195	9170	9144	9117	9090
726	9459	9439	9416	9394	9373	9350	9327	9304	9280	9256	9232	9208	9183	9157	9130	9103
728	9472	9451	9428	9406	9385	9362	9339	9316	9292	9268	9244	9220	9195	9169	9142	9115
730	9484	9463	9441	9419	9398	9375	9352	9329	9305	9281	9257	9233	9208	9182	9155	9128
732	9496	9475	9453	9431	9410	9387	9364	9341	9317	9293	9269	9245	9220	9194	9167	9140
734	9508	9487	9465	9443	9422	9399	9376	9353	9329	9305	9281	9257	9232	9206	9180	9153
736	9520	9499	9478	9456	9434	9411	9388	9365	9342	9318	9294	9270	9244	9218	9192	9166
738	9532	9511	9490	9468	9446	9423	9400	9377	9354	9330	9306	9282	9256	9230	9204	9178
740	9544	9523	9502	9480	9459	9436	9413	9390	9367	9343	9318	9294	9268	9243	9216	9190
742	9556	9535	9514	9492	9471	9448	9425	9402	9379	9354	9330	9306	9280	9255	9228	9202
744	9569	9547	9526	9504	9483	9460	9437	9414	9391	9366	9342	9318	9292	9267	9241	9214
746	9580	9559	9537	9516	9494	9472	9449	9426	9403	9379	9355	9331	9305	9280	9254	9227
748	9592	9571	9549	9528	9506	9483	9461	9438	9415	9391	9367	9343	9317	9292	9266	9239
750	9603	9583	9561	9540	9518	9495	9473	9450	9427	9403	9379	9355	9330	9304	9278	9251
752	9615	9594	9573	9551	9530	9507	9485	9462	9439	9415	9391	9367	9342	9316	9290	9263
754	9627	9606	9585	9563	9541	9519	9497	9474	9451	9427	9403	9379	9354	9328	9303	9275
756	9639	9618	9596	9575	9553	9531	9509	9486	9462	9439	9415	9391	9366	9340	9315	9288
758	9651	9630	9608	9587	9565	9542	9521	9498	9474	9450	9427	9403	9377	9352	9327	9300
760	9662	9641	9620	9598	9577	9554	9532	9509	9486	9462	9439	9415	9389	9364	9339	9312
762	9674	9653	9632	9610	9588	9566	9544	9521	9498	9474	9451	9427	9401	9376	9351	9324
764	9685	9665	9643	9621	9600	9578	9556	9532	9509	9486	9463	9438	9413	9388	9363	9336
766	9697	9676	9655	9633	9612	9589	9568	9544	9521	9498	9474	9450	9425	9400	9375	9348
768	9709	9688	9666	9645	9623	9601	9579	9556	9533	9509	9485	9462	9436	9411	9386	9360
770	9720	9699	9677	9656	9635	9613	9590	9567	9545	9521	9497	9473	9448	9423	9398	9372
772	9732	9711	9689	9668	9646	9624	9602	9579	9556	9533	9509	9485	9460	9435	9409	9384
774	9743	9722	9700	9679	9658	9636	9613	9591	9568	9545	9521	9497	9472	9446	9421	9396
776	9755	9734	9712	9691	9670	9647	9625	9602	9579	9556	9532	9508	9483	9458	9433	9407
778	9766	9745	9723	9702	9681	9658	9636	9614	9591	9567	9544	9520	9495	9470	9445	9419
780	9777	9756	9735	9714	9692	9670	9648	9625	9602	9579	9555	9532	9506	9481	9456	9430

TABLE 5.

Factor for Reducing Volume of Gases to Standard Temperature and Pressure, Dry; Including Reduction of Barometric Height to Standard Temperature (brass scale).

	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
700	0.855	851	847	842	838	834	829	825	821	816	812	807	802	797	793	788	783	778
702	857	853	849	845	840	836	832	827	823	818	814	809	805	800	795	790	785	780
704	860	856	852	847	843	839	834	830	825	821	816	812	807	802	797	792	787	783
706	862	858	854	850	845	841	837	832	828	823	819	814	810	804	800	795	790	785
708	865	861	856	852	848	843	839	834	830	825	821	816	812	807	802	797	792	787
710	867	863	859	855	850	846	842	837	833	828	824	819	814	809	804	799	795	790
712	870	866	861	857	853	848	844	839	835	830	826	821	817	812	807	802	797	792
714	872	868	864	859	855	851	846	842	837	833	828	824	819	814	809	804	799	794
716	875	871	866	862	858	853	849	844	840	835	831	826	822	816	812	807	802	797
718	877	873	869	864	860	856	851	847	842	838	833	828	824	819	814	809	804	799
720	880	876	871	867	863	858	854	849	845	840	836	831	826	821	816	812	807	802
722	882	878	874	869	865	861	856	852	847	843	838	833	829	824	819	814	809	804
724	885	880	876	872	867	863	858	854	849	845	840	835	831	826	821	816	811	806
726	887	883	879	874	870	866	861	856	852	847	843	838	833	829	824	818	813	808
728	890	886	881	877	872	868	863	859	854	850	845	840	836	831	826	821	816	811
730	892	888	884	879	875	871	866	861	857	852	847	843	838	833	828	823	818	813
732	895	890	886	882	877	873	868	864	859	854	850	845	840	836	831	825	820	815
734	897	893	889	884	880	875	871	866	862	857	852	847	843	838	833	828	823	818
736	900	895	891	887	882	878	873	869	864	859	855	850	845	840	835	830	825	820
738	902	898	894	889	885	880	876	871	866	862	857	852	848	843	838	833	828	822
740	905	900	896	892	887	883	878	874	869	864	860	855	850	845	840	835	830	825
742	907	903	898	894	890	885	881	876	871	867	862	857	852	847	842	837	832	827
744	910	906	901	897	892	888	883	878	874	869	864	859	855	850	845	840	834	829
746	912	908	903	899	895	890	886	881	876	872	867	862	857	852	847	842	837	832
748	915	910	906	901	897	892	888	883	879	874	869	864	860	854	850	845	839	834
750	917	913	908	904	900	895	890	886	881	876	872	867	862	857	852	847	842	837
752	920	915	911	906	902	897	893	888	883	879	874	869	864	859	854	849	844	839
754	922	918	913	909	904	900	895	891	886	881	876	872	867	862	857	852	846	841
756	925	920	916	911	907	902	898	893	888	883	879	874	869	864	859	854	849	844
758	927	923	918	914	909	905	900	896	891	886	881	876	872	866	861	856	851	846
760	930	925	921	916	912	907	902	898	893	888	883	879	874	869	864	859	854	848
762	932	928	923	919	914	910	905	900	896	891	886	881	876	871	866	861	856	851
764	935	930	926	921	916	912	907	903	898	893	888	884	879	874	869	864	858	853
766	937	933	928	924	919	915	910	905	900	896	891	886	881	876	871	866	861	855
768	940	935	931	926	922	917	912	908	903	898	893	888	883	878	873	868	863	858
770	942	938	933	928	924	919	915	910	905	901	896	891	886	881	876	871	865	860
772	945	940	936	931	926	922	917	912	908	903	898	893	888	883	878	873	868	862
774	947	943	938	933	929	924	920	915	910	905	901	896	891	886	880	875	870	865
776	950	945	941	936	931	927	922	917	912	908	903	898	893	888	883	878	872	867
778	952	948	943	938	934	929	924	920	915	910	905	900	895	890	885	880	875	869
780	955	950	945	941	936	932	927	922	917	912	908	903	898	892	887	882	877	872

Form 1. METABOLISM LABORATORY MAYO CLINIC

Case No. A...

Date

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Name

Gasom. No.....

Samp. Set

Barometer	mm.	Log. % CO ₂ produced		
Temp. Gasom.	°C.	Log. % O ₂ absorbed	_____	
		Log. Resp. Quot. (sub.)	=	R.Q.
Gasom. { End	cm.			
{ Start	cm.	Log. Fact. Gasom.	.0992	
{ Diff. (sub.)	cm.	Log. Gasom. diff.	_____	
Duration of test .. m.	s. =	Log. Fact. S. T. P. D.	_____	
	min.	Log. Total vent. (add)	_____	
CO ₂ Expired	%	Log. Time	_____	
CO ₂ Inspired	0.04%	Log. Vent. per min. ... (sub.)	=	L.
		Log. % O ₂ absorbed	_____	
CO ₂ Produced (sub.)	%	Log. O ₂ Absorbed (add)	=	cc.
		Log. Cal. value O ₂ +log. 60 ..	_____	
O ₂ Inspired, corr.	%	Log. Total Cal. per hr. (add)	=	Cal.
O ₂ Expired	%	Log. Surface area	_____	
O ₂ Absorbed (sub.)	%	Log. Cal. per sq. m. hr. (sub.)	=	Cal.
	B. M. R.	%		

Analysis by:	Haldane No.:	Analysis by:	Haldane No.:	Avg. CO ₂
				Avg. O ₂
				CO ₂ +O ₂
				NOTES:
Log. CO ₂ diff.	Log. O ₂ diff.	Log. CO ₂ diff.	Log. O ₂ diff.	
Log. sample. _____	Log. sample. _____	Log. sample. _____	Log. sample. _____	
Log. CO ₂ % ..	Log. O ₂ % ...	Log. CO ₂ % ..	Log. O ₂ % ...	
CO ₂ %	O ₂ %	CO ₂ %	O ₂ %	
Analysis by:	Haldane No.:	Analysis by:	Haldane No.:	
Log. CO ₂ diff.	Log. O ₂ diff.	Log. CO ₂ diff.	Log. O ₂ diff.	Readings by:
Log. sample. _____	Log. sample. _____	Log. sample. _____	Log. sample. _____	Checked by:
Log. CO ₂ % ..	Log. O ₂ % ...	Log. CO ₂ % ..	Log. O ₂ % ...	Calculations by:
CO ₂ %	O ₂ %	CO ₂ %	O ₂ %	First check by:
				Second check by:

8-814-W

The normal basal calories per day for an individual is, however, the minimum requirement, and to this must be added an assumed amount to allow for the individual's muscular activity and for the specific dynamic action of the food. This allowance, necessarily, remains arbitrary and will vary mainly with the amount of muscular activity of the individual which, for a hospitalized patient, is not far from 20 per cent. to 30 per cent. of the basal requirements.

To use chart 6, place the needle on the appropriate weight (53.1 kg.), bring the left end of the ruler over the appropriate height (155 cm.), and place the needle on the point where the ruler crosses the surface area scale (1.50 sq. m.); if this is already known, the determination may start from this point; with the needle as pivot, swing the rule to the individual's normal standard if his basal metabolic rate is within normal

limits or to the calories per square meter per hour, if determined experimentally (58.4 cal. per sq. meter per hour) and read the answer on the scale for total calories per day (2100 cal.). The minimum requirement, then, for the individual is 2100 calories a day; to this add 20 or 30 per cent. to allow for muscular exertion and the specific dynamic action of the food ingested, making a total calorific requirement between 2500 and 2700 calories per day, depending on the activities of the patient. The addition of 20 or 30 per cent. can be done rapidly by writing down the basal calories and placing underneath the product obtained by mental multiplication by 0.2 or 0.3 and adding as follows:

2100	2100
420	630
2520	2730

This chart has been found valuable by our dietitian, Miss Foley, in quickly calculating the patient's daily food requirement. By its use, a high, average or low caloric diet for any individual may be determined with exactness and rapidity.

SUMMARY.

1. The reasons for our preference of the gasometer method of indirect calorimetry for clinical work are briefly given.

2. A series of nomographic charts are described by which the calculation of basal metabolic rate from the data obtained by the gasometer method can be made graphically in less than five minutes without the use of logarithms.

3. The methods of construction and use of nomographic charts are given.

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THE HOSPITAL AS A DIAGNOSTIC CENTRE.*

BY ERNEST L. HUNT, M.D., WORCESTER, MASS.

THE many recent attempts at legislation tending to socialize medicine evidence a feeling abroad in the land that the full possibilities of medical science to alleviate the physical distresses of mankind are not being fully realized. The inadequacy of the practice of medicine as at present organized, to reach all sufferers with its full measure of relief, is recognized, and it is quite natural that the lay student of the situation should attribute the cause to lack of ability to pay for the services of a doctor or to a niggardly spirit which urges people to refrain from calling a doctor until too late rather than to spend the amount of the fee, as he thinks, needlessly.

The lay student and the legislator who seek to devise a remedy are apt to start with the premise that to provide the patient with the resources of medical science, it is only necessary to provide the means of having a doctor and, perhaps, a nurse; in other words, they regard the fee as the great obstacle to adequate service, and so by various insurance devices they contemplate its removal.

If the premise were wholly, as we must admit it is partly, true, and the remedy so simple,

* Read before the Worcester District Medical Society at a meeting held in the Out-Patient Building, Worcester City Hospital, April, 1921.

there would yet remain the difficulty of providing the means to pay the fees and the organization to administer the distribution of the calls and the fees, all of which opens such vast possibilities of inefficiency, graft, bureaucracy, taxation and meddling in the private affairs of both patient, doctor and citizen, as fortunately to appall the average taxpayer. The costliness and inadequacy of the Government's attempt to care for the disabled soldiers is a splendid object lesson in this relation.

But as we well know, the premise is, to say the most for it, but partly true. Today in Massachusetts, the standards provided by law are so low and the title "Doctor," with legal right to practice, have been so easily acquired that, as regards the degree to which the practitioner is representative of and capable of expressing the best in medical science, one can only say that there is wide variation and, indeed, that about the only thing the different groups of practitioners have in common is the right to practice under the law.

Moreover, the second part of the premise is defective inasmuch as by far the greatest reason for neglect to seek the advice and aid of the physician lies in the lack of popular knowledge of conditions which call for the help of a medical advisor, to say nothing of the superstitious preferences for various forces of quackery, of prejudice and folly. How common is the patient who neglects or maltreats an infected wound under the delusion that his particular flesh possesses unusual healing power!

So it has come about that the better elements of our profession as represented by our state societies, are generally opposed to so-called health insurance, but as yet are unprepared to meet the propaganda of the proponents with counter propositions of greater or more evident merit.

I claim no originality in perceiving the need of a program on the part of established institutions to meet the new demands. Boston Dispensary, with its "health," and Massachusetts General, with its "consultation" clinics, are in mind as I write. Warbasse, in his recent textbook, devoted a chapter to the economies of surgical practice, in which he dwells upon possible developments to this end. Throughout the state and nation, vast plans for improved medical schools, health departments, etc., are now being made and realized. The custom of group practice is spreading rapidly and is destined to partially answer the question as to how the patient of moderate means can secure the services of the specialists his case may demand.

In our older communities, however, this innovation does not take root so rapidly and, indeed, there would still remain a large percentage of the population unable to avail themselves of the group idea unless it were organ-