FACTORS INFLUENCING THE CORRELATION BETWEEN DIFFERENCES OF ELECTRIC POTENTIAL IN THE SKIN OF HUMAN SUBJECTS AND BASAL METABOLISM

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Plate 57

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In a preliminary report on the relationship between electric differences of potential in the skin and normal basal metabolism we (4) concluded that, within the range of normal basal metabolism (+10 per cent to −10 per cent), there appears to be a definite correlation between the basal metabolic rate and the differences of electric potential in the skin of human subjects provided there is no marked impairment (either retardation or acceleration) in the circulation of the blood or in the physiologic functioning of the skin. We have continued our investigations regarding the factors which influence the correlation between the cutaneous electric differences of potential and basal metabolism.

Lund in 1927 and 1928, in his researches on the respiration of cells reported that the electric polarity of a cell bears a quantitative relationship to the respiratory changes of the cell. Since electric currents accompany cell oxidation, he believed that these currents were the result of oxidation-reduction potentials developed by the respiratory mechanism of the cells.

Aveling and McDowall, from a study of the cutaneous blood vessels of animals, concluded that the resistance of the skin may be used as an indication or measurement of its vascularity. A decrease in resistance was associated with vasoconstriction, and vasodilatation was associated with an increase in resistance. Wells supported these conclusions by his observations on the skin of human subjects.

At an earlier date Waller concluded that there was a close association between nutritional changes and the values of the electric resistance of the skin, but cor-

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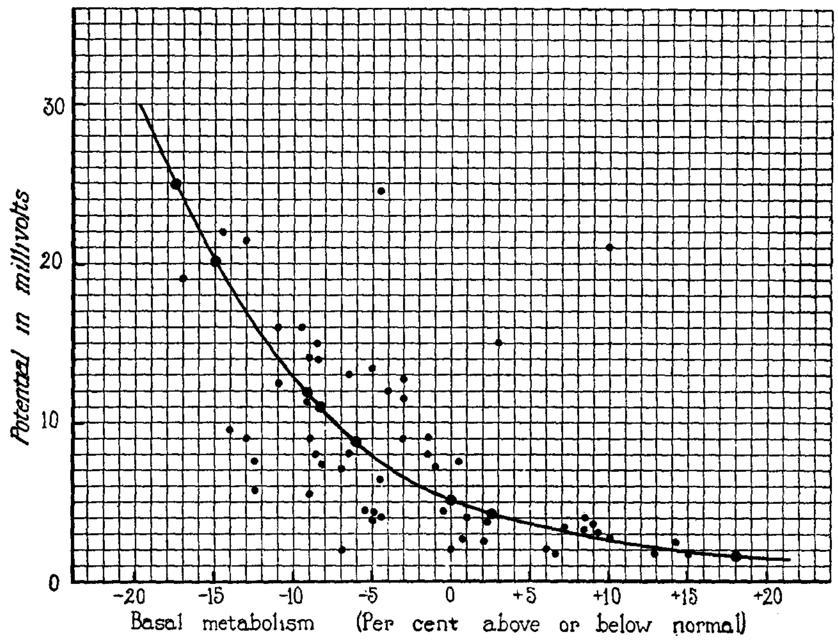
relation was not attempted between electric conductance and general metabolic activity.

EXPERIMENTAL PROCEDURES AND RESULTS

In Text-fig. 1 are plotted the values of the differences of electric potential as ordinates with the corresponding basal metabolisms, expressed in percentages, above or below normal, as abscissae in a group of persons presumably normal.



TEXT-FIG. 1. Correlation between the differences of electric potential and the basal metabolic rates in a group of normal persons.

The figure indicates a general tendency to grouping with some marked deviations. The curve, which was drawn from a consideration of all the data, is of the general type

$$y = b\ e^{cx} \qquad \text{(Formula 1)}$$

With the insertion of the proper constants after transformation, this equation becomes

$$x = \frac{\log y - \log 0.005}{-\ 0.0396} \qquad \text{(Formula 2)}$$

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where x is the basal metabolic rate and y is the difference of electric potential of the skin measured across a specified intervening area of skin. The data of Text-fig. 1 show that higher basal metabolic rates are accompanied by lower differences of potential, and *vice versa*.

Fig. 1 of the plate depicts the room and the ensemble of apparatus used in our investigations. The standard open circuit type of gasometer for the determination of basal metabolism and the apparatus containing samples of expired air collected above mercury in tubes are shown at the left of the figure. The mask is in position over the mouth and nose of the person under test. In the right portion of the illustration is shown the electric ensemble for the measurement of potential difference. The non-polarizable electrodes of Alvarez, Clark and Freelander are shown in position on the skin of the outer side of the left forearm. One electrode is placed at the articulation of the ulna and radius, while the second electrode is placed at an arbitrarily chosen but fixed distance of 12 cm. from the first electrode. Certain previous investigators believed that electric readings on the skin were influenced by sudomotor variations. We used a portion of the skin containing relatively few sweat glands in order to minimize any such effect. All measurements were made on persons who complied with standard requirements for the basal metabolic rate. Readings on the difference of electric potential were taken during the period of rest immediately preceding the test for basal metabolism. The potential differences were measured with the Leeds and Northrup potentiometer shown in the plate (at the right in Fig. 2). This instrument was used in connection with the galvanometer (Leeds and Northrup, Type R, 2,500, *a*) and in the plate is shown mounted on the wall in the upper right corner of Fig. 1. A portion of the electric measurements of potential were made with a combination of a portable galvanometer and millivoltmeter (left side of Fig. 2). The measurements obtained by the potentiometer and the millivoltmeter were invariably in agreement, but the portable millivoltmeter-galvanometer combination is not as readily adjusted.

A diagrammatic sketch of the non-polarizable electrode, with indications of the materials used in its construction, is shown in Text-fig. 2. The electrode is filled with a solution of lead chloride. Electric connection with the potentiometer is made through the two mercury amalgams (Cu + Hg and Pb + Hg). Contact with the skin is made through the gauze wick shown at the left of the figure.

After the electrodes had been in position for a few minutes (8 to 10) on the arm of the person under test, the difference of potential generally reached a fairly steady or constant value; if it did not, an average or a modal value was used. The true difference of electric potential then was obtained by subtracting the potential of the electrodes *per se* from the constant value of the potential difference in position on the forearm. Text-fig. 3 shows typical sets of data. At times there is a rise of potential difference to the steady value, as shown in Curves 1 and 2, whereas at other times, as shown in Curve 4, there is a decrease in the value of the potential difference before the constant state is reached. Curve 3 is an example taken from

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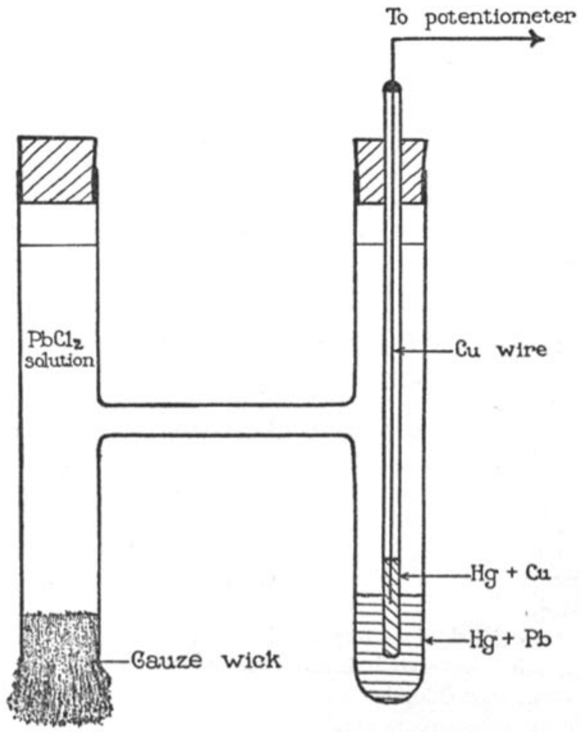
a small group of data in which the potential difference did not reach or maintain a definite constant value.

Most of the data on the basal metabolic rates were determined with an open circuit type of gasometer and analyses of the expired air by the method of Haldane. The closed circuit types of apparatus for measuring oxygen consumption (Benedict-Roth and Sanborn) also were used in these investigations. A subsequent report will be made regarding the discrepancies between the open and closed types



TEXT-FIG. 2. Sketch showing the construction of a non-polarizable electrode

of instrument and the possible reasons for these discrepancies with suggestions for their correction.

Text-fig. 4 (1 to 6) shows redrawn tracings taken from tests made on a closed circuit type of apparatus: each portion is obtained during 2 minutes of the period of test. Graphs 1 and 3 exhibit exceptionally regular breathing, Graph 2 is typical of irregular or erratic breathing, Graphs 4 (hypothyroidism) and 6 evidence a slow rate of respiration, and Graph 5 is the record of the breathing of a person with hyperthyroidism.

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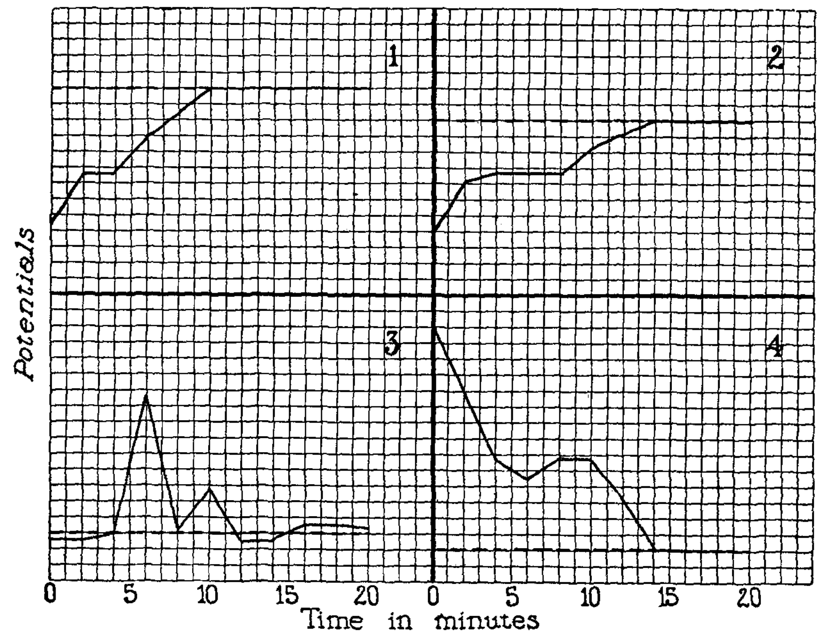
In a previous communication we reported that the data, obtained by the methods described, were divisible into three groups: (1) rates showing a correlation between differences of electric potential in the skin and basal metabolic rates such as are exhibited by normal persons, (2) rates above the normals, and (3) rates below the normals. With few exceptions the basal metabolic rates calculated by the use of Formula 2 did not agree with the experimentally determined values of the



TEXT-FIG. 3. Characteristic types of curves showing the relationship between time (in minutes) and the potential (in millivolts) before the steady state is reached.

metabolic rates which fell either above +13 per cent or below −10 per cent. The agreement of rates, as determined by calculation from Formula 2 and by gasometric test, within the normal range of +10 per cent and −10 per cent, was within ±4 points. In fact, we have used Formula 2 in attempts to predict the basal metabolism, believing that normal, healthy persons with normal circulation of blood and normal physiologic functioning of the skin manifest a definite corre-

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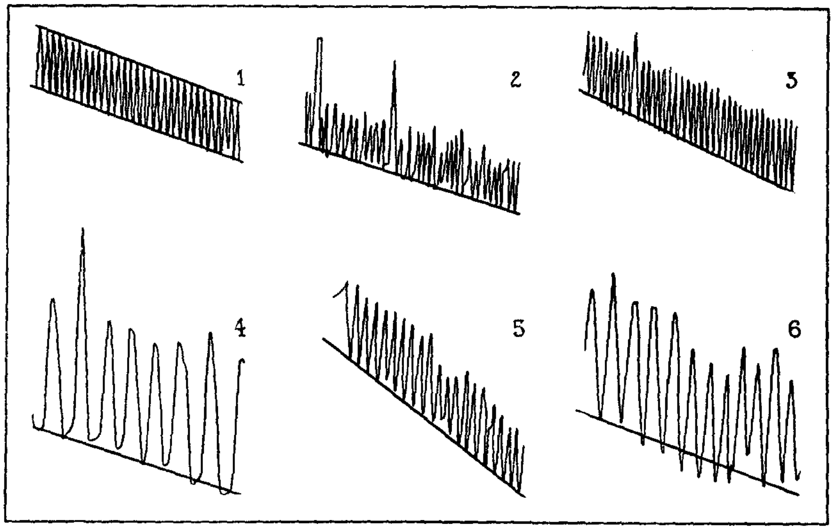
lation between basal metabolism and differences of electric potential, and that appreciable departure from correlation is indicative of abnormality of the circulation of the blood or of the functions of the skin.

Analysis of Clinical Observations Indicative of Factors Affecting the Correlation between Electric Potentials and Basal Metabolic Rates

We have added to the data previously obtained a number of observations in which extremely high or low values of difference of electric



TEXT-FIG. 4. Redrawn tracings taken from tests made with a closed circuit type of metabolic apparatus. Graph 1 represents exceptionally regular breathing; Graph 2, erratic breathing; Graph 3, regular breathing; Graph 4, hypothyroidism with slow breathing; Graph 5, hyperthyroidism, and Graph 6, slow breathing.

potential or basal metabolic rates were exhibited. In almost all of these observations the metabolic rates, obtained by calculation from Formula 2 and by direct determination, have not agreed within the range of ± 4 points. The lower curve of Text-fig. 5 shows the percentage of agreement between the calculated and experimentally determined values of the basal metabolism for the number of cases in each group as shown in the upper curve of the figure. The data include

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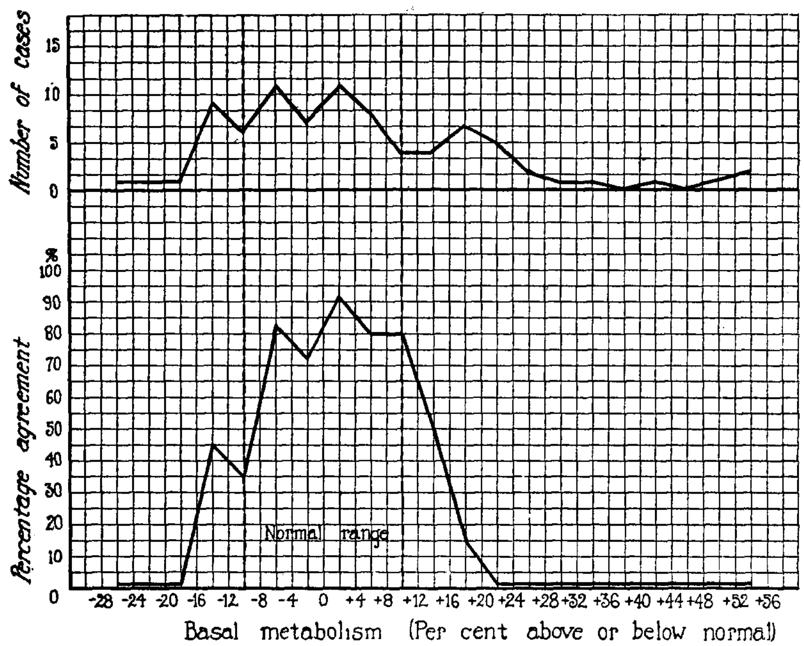
measurements on eleven normal persons and on 72 persons who had presented themselves for clinical examinations. From a consideration of the distribution of values and of the fact that we were measuring differences of electric potential and basal metabolic rates of the group of 72 persons, we were led to a survey of the records. In the basal metabolic rates of this group as determined by test, eight were



TEXT-FIG. 5. The lower curve shows the percentage of agreement between the basal metabolic rates determined by gasometric methods and from calculations on data obtained on the differences of electric potential for the number of cases in each group shown in the upper curve. (Data concerning 83 persons; 11 normal and 72 clinical subjects.)

below −10 per cent, forty were within the normal range and twenty-four were above +10 per cent.

In cases in which the metabolic rates fell below −10 per cent there was one case only in which the rates, determined by the two methods, agreed within ±4 points. In the clinical data regarding the other seven cases in this group there were recorded, in addition to the usual

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symptoms accompanying lowered metabolism (such as dry, cold skin, and so forth), migraine with edema, one case each of angina pectoris and of anemia and one case in which the patient stated that the hands and feet go to sleep frequently and easily.

There were twenty-one of the twenty-four basal metabolic rates above +10 per cent which did not agree within ±4 points. In these twenty-one cases there were reported symptoms of hyperthyroidism, such as marked nervousness, palpitation, tachycardia or edema. A diagnosis of subacute lymphatic leukemia was made in the case of one person whose basal metabolic rate was high but who had no symptoms of hyperthyroidism. Besides the symptoms of hyperthyroidism there were reported in this group five cases of hypertension. Chronic nervous exhaustion, endocarditis, pericarditis, myocardial insufficiency, aortic sclerosis, secondary anemia and migraine also were noted. Five of the persons in this group had been placed on treatment with iodine for some time previous to the metabolic tests, hence the rates as determined may be considered as artifacts.

Within the normal range there were ten exceptions to the agreement in metabolic rates by the two methods. In one of these exceptions the metabolic rate was taken shortly after thyroidectomy; in another the rate was associated in all probability with a condition of dyspnea. Two persons reported amenorrhea and frequent fainting spells. Two patients had been on treatment with thyroxine for some time, one of these had been given a diagnosis of myxedema with hypertension and cardiac hypertrophy, and the other had taken considerable amounts of calomel during the 2 years immediately preceding, in which she had suffered from cholecystitis and anorexia nervosa. The history of one of the patients in this group carried a diagnosis of colloid goiter and mitral stenosis. In another instance, aortic sclerosis and diabetes mellitus were reported. One man, with symptoms of hyperthyroidism and pericarditis, had a low metabolic rate due to the administration of iodine; previously he had had two attacks of lobar pneumonia with circulatory disturbances and slow recovery to normality in this particular. One case of adenomatous goiter and cholecystitis also was found in this group, but there was nothing of significance by way of an explanation for the disagreement between

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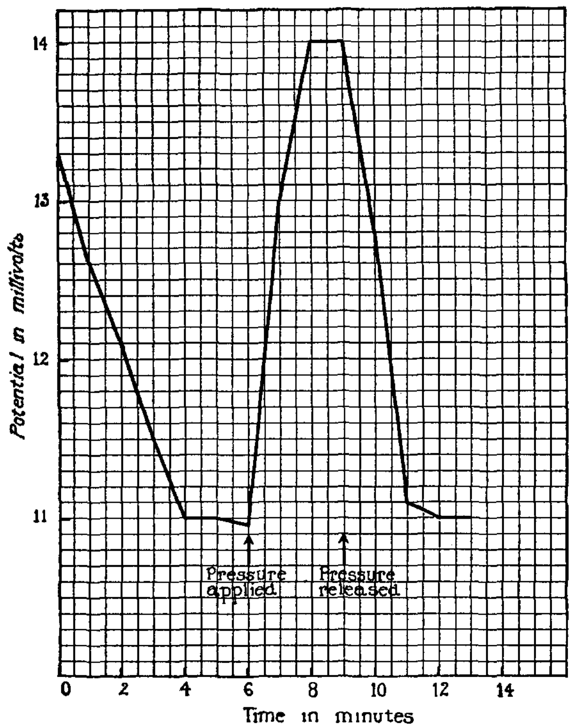
the metabolic rate as determined from the electric potentials in the skin and the directly determined value.

As a further check on our investigations, the data regarding persons whose metabolic rates as determined by the two methods were in agreement within ±4 points were examined. Four persons had a rate



TEXT-FIG. 6. Curve showing the effects of the application and release of pressure on the values of the differences of electric potentials (in millivolts) across a given area of skin.

outside the normal range. One person had a rate of −12 per cent and was given a diagnosis of adenomatous goiter and cholecystitis. Three persons had metabolic rates above normal, between +10 and +18 per cent, which for purposes of this investigation, may be considered as of negative significance. In the large group within the normal range, the only cases of significance were those of mild hyper-

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tension, one case of moderate aortic sclerosis and several cases of adenomatous goiter without hyperthyroidism.

In general, therefore, these investigations show that there are abnormalities in the circulatory system of the blood or in the functions of the skin of persons for whom the metabolic rates determined by the two methods (electric potentials in the skin and gasometric) do not agree. Since abnormality of the circulation of the blood and of the functions of the skin accompanies high and low metabolic rates in which there is marked disagreement, it is probable that such dysfunctions may serve as an explanation of the few instances in which the observed metabolic rates within the normal range did not correspond to the values predicted from the measurements on the differences of electric potentials.

Hyperthyroidism, as manifested by high basal metabolic rates, is accompanied by acceleration of the circulation of the blood, whereas retardation in the circulation is accompanied by hypothyroidism and low metabolic rates. We have made experimental tests which definitely show the marked changes in electric potentials caused by artificially produced changes in the normal circulation of the blood. Text-fig. 6 shows that there was a rapid increase in the value of the difference of electric potential across two chosen areas of the skin of the forearm when the circulation was temporarily cut off with pressure produced in the sphygmomanometric cuff. The difference of electric potential returned to its former normal value quickly after the release of the pressure.

Other deductions presumably may be drawn from the data thus far obtained. An inverse correlation apparently exists between cutaneous temperature and differences of electric potential. This deduction suggests the possibility of other investigations which may be of clinical significance. Furthermore, there is a correlation between the difference of electric potentials and the metabolic rates which seems to obtain under other than basal conditions. Eating breakfast and exercise do not appear to change the relationship. Day by day variations, temporary emotional changes and the partaking of food seem to affect the predicted rates less than they affect the usual (gasometric) observed rates. One example from several that might be cited clearly shows the part that emotion may play. It is that of a woman

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whose first basal metabolic rate was recorded as −20 per cent with a subsequent rate of −7 per cent, whereas the rate predicted from the measurements on electric potentials, Formula 2, made just prior to the first test gave a value of −8 per cent.

Recently we have carried on a series of investigations in which we obtained data on metabolic rates under other conditions than basal, differences of electric potentials at various periods of the day and under both constant or varied environmental conditions, blood pressure, pulse rate, respiration and cutaneous temperature. The results and conclusions from these data concerning normal persons and persons presenting abnormal conditions of skin and of the vasomotor and circulatory systems will be presented in another study.

SUMMARY

High metabolic rates are associated normally with small differences of electric potential, whereas low metabolic rates are associated with large differences of electric potential as measured on the extremities of the body.

Within the normal range of metabolism there appears to be a definite correlation between the metabolic rates and the difference of electric potential over a specified area of the skin, provided the person under test has no abnormalities of the circulatory system or of the functions of the skin.

If there are no dysfunctions of the circulation or of the skin, the metabolic rate may be calculated, within ±4 points, from the expression

$$x = \frac{\log y - \log 0.005}{-0.0396}$$

where x is the metabolic rate and y is the difference of electric potential across the specified areas of skin (electrodes 12 cm. apart).

In general, there are abnormalities of the circulation of the blood or of the functions of the skin of persons for whom the metabolic rates determined by the two methods (difference of electric potentials and gasometric procedures) do not agree with ±4 points.

Manifest retardation or return to normality in the rate of circulation of the blood, such as may be produced by the sphygmomanometric cuff under varying pressures, produces marked changes in the difference of electric potentials obtained across a specified intervening area

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of skin. Retardation of flow of blood produces increased differences of electric potential.

Preliminary investigations indicate that there is an inverse correlation between cutaneous temperatures and differences of electric potential.

Day by day variations, emotive effects and the partaking of food have less effect, in general, on the electric potentials across a specified area of skin than they have on the metabolic rates.

These experimental results indicate that there may be a more direct correlation between electric potentials and the circulation of the blood *per se* than between electric potentials and the metabolism of the body *per se*. When normality of circulation of the blood and of the functions of the skin exists in the areas under test for differences of electric potential, there is apparently a correlation between metabolic rates and electric potentials.

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EXPLANATION OF PLATE 57

FIG. 1. Ensemble of apparatus for the determination of basal metabolic rates by gasometric methods (left side) and by the differences of electric potential (right side).

FIG. 2. Millivoltmeter and non-polarizable electrodes (left side) and the potentiometer (right side) used in the measurements of electric potentials.

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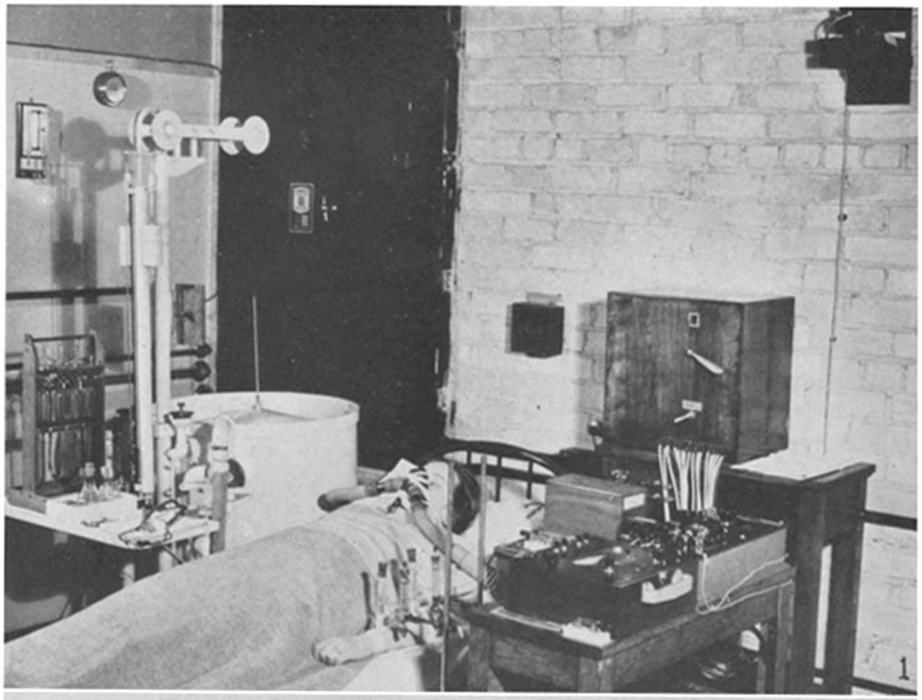

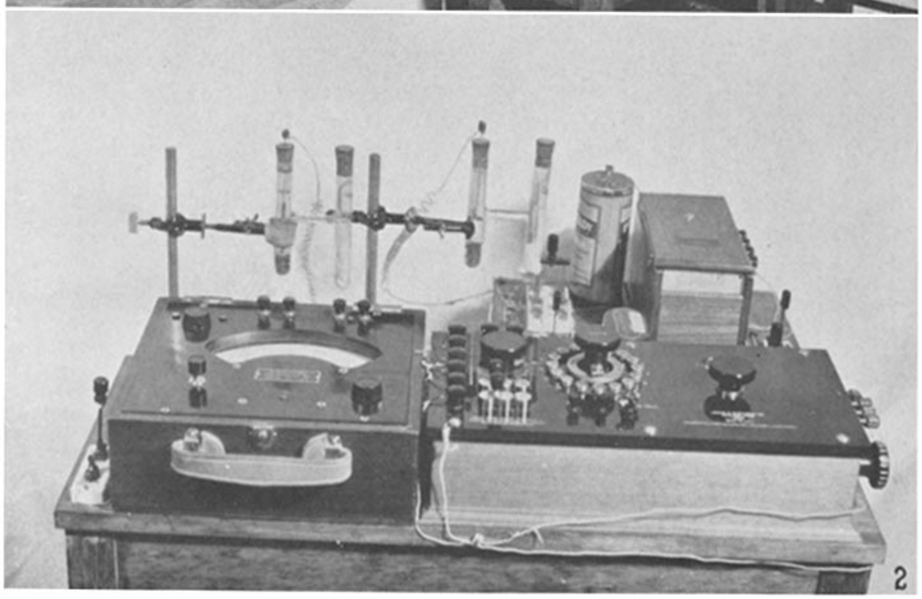

(Purdy and Sheard: Electric potential and basal metabolism)

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