DIFFERENTIAL METHOD FOR RECORDING
THE RATE OF WATER EVAPORATION
IN A SMALL SKIN AREA

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Continuous recording of water discharge from the skin in its detailed figure of fluctuations was often taken as necessary for investigation of cutaneous perspiration. Though there have been hitherto reported so many methods for measurement of water evaporation from a small skin area, most of them are for discontinuous estimation of it. As far as continuous or semi-continuous recordings are concerned, only a few methods were demonstrated by investigators such as PALMES5, NAKAYAMA and TAKAGI3, HEERD and OHARA2, PIRLET6, CUSTANCE1 and WILCOT7. Nevertheless, the requirement, accurately and continuously to register minute water discharge from the skin, is not yet satisfactorily fulfilled. New apparatus for this purpose were therefore devised and some experiments were made by means of them.

IMPROVEMENT OF APPARATUS

1. Registration of weight increase of desiccant material in the absorption capsule by the micro-balance (gravimetric method).

A gravimetric method was previously reported by the author and KONDO4 for measurement of minute water absorbed by desiccant materials in a absorption capsule by means of a micro-balance. In this method, weight of water absorbed in the desiccant material was estimated by measuring the moving distance of a light figure which was reflected on a small mirror attached to the balance pan and thrown upon a distant measure scale. This micro-balance method was the basic type for further reformation.

(1) Conversion of the light spot displacement into electrical values. As direct recording of the reflected light figure from the mirror was considerably difficult owing to its minute vibrations originated from pulsatory body movements or any other sources, the light displacement had to be converted

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into some other measure suitable for registration. To avoid this disadvantage, the light figure moving on the scale was traced manually by means of a sliding apparatus (Fig. 1) which was, on the other side, connected to a slide resistor (Rv in Fig. 1 and 2) of a Wheatstone bridge. Thus, the weight increase of the desiccant material could be recorded electrically as unbalanced potential of the bridge circuit.

(2) Registration of integrate values of water evaporation. Changes of unbalanced potential of the bridge was recorded using the circuit (a) in Fig. 2. The obtained curve represents the integrate value of the weight increase of the desiccant as water absorption goes on, the gradient of the curve showing the rate of water absorption in the desiccant, namely, that of water evaporation from the skin.

(3) Registration of differential values. Simple registration of integral values was found to be unsuitable to obtain distinct and substantial informations about detailed figure of evaporation, as one can see in an example of Fig. 9. Development of an apparatus for recording differential values was required.

Changes of unbalanced potential of the bridge in a certain length of time (20 seconds) was registered serially by using a differentiation apparatus basing on the following principle illustrated in Fig. 2. Three electrical condensers of the same capacity were used. These condensers (C₁, C₂, C₃) were
alternately charged by the unbalanced potential fed from the bridge and discharged in the serial order as illustrated in Fig. 3. At a moment of time, condenser $C_1$ and $C_3$ are charged, then, the subtraction between the charged electricity of $C_1$ and $C_3$, the latter having been charged 20 seconds prior and preserved, is performed by means of making the circuit connecting $C_1$ and $C_3$, after reversing polarity of $C_3$. The residual electricity of the system $C_1$ and $C_3$ is discharged through a resistor (200 KΩ in Fig. 2). The potential
Fig. 4. Diagram of relay circuit with motor driven rotatory switch. C: contact for charging, D: contact for discharging. For condensor of 50µF see text.

Fig. 5. Recording demonstrating relationship between integral and differential values. A calibration experiment. Upper record: differential values. Height of spike deflection represents weight increase of desiccant material in 20 seconds. Lower record: integral value which represents increase of desiccant weight with time.
fall over this resistor is amplified and registered. Charged electricity of $C_2$ is, meanwhile, preserved for the next differentiation. The next coming charging is performed with $C_1$ and $C_3$, then, the subtraction is made between $C_1$ and $C_2$, $C_3$ being meanwhile preserved, and so on. The switching on and off of charging or discharging the main circuit was acted by electromagnetic relay switches at interval of 10 seconds, the current to drive them being fed by means of a motor driven rotatory switch. Double relay switches $S_2$, $S_4$, $S_5$ and $S_6$ are made on or off in combination with switching of the main circuit. The whole arrangement of the switch system is demonstrated in Fig. 2 and 4. A sufficient length of time must be allowed for the process of subtraction between two condensers $C_1$ and $C_2$ or $C_3$. For this purpose, condenser of 50 $\mu$F in Fig. 4 was used which contributes to ensure a delay of time of about 65 msec. from the time of onset of switch $S_4$ or $S_6$ to that of switch $C_2$. A sample recording for relationship between registrations obtained as integral values and differential values is shown in Fig. 5.

2. Automatic registration of the rate of water absorption of the desiccant material (electrical conductance method).

Although the micro-balance method above mentioned was thought to be a conspicuous and unique technique with accuracy and high sensitivity, it involves manipulative procedures and its application must be restricted to some selected body regions owing to its measuring principle of gravimetry. In order to compensate these unfavorable points, the following device of electrical conductance method was developed. The principle is to record the

![Diagram](image-url)
changes of electrical resistance of the desiccant material during the course of water absorption. The diagram of the apparatus is shown in Fig. 6. As the desiccant material, a mixture of 5 parts of glycerine in weight and 3 parts of finely pulverized crystal of lithium chloride was found to give the most reliable and stable results among several sorts of desiccant materials and solvents which were examined: A piece of filter paper which was spread over with the desiccative mixture was applied to the capsule, so as the painted side contacts with the electrodes. During the whole procedures, care must be taken to prevent the desiccant material from intermixture of moisture from any sources but the skin. A current was supplied through the desiccant material from the source of 60 cps and 12 volts and, after rectification of the output current, its strength was recorded by means of the differentiation apparatus mentioned above. The calibration experiments was performed in the following manner: The capsule was laid upon filter paper wetted with H2O or a satulated solution of various salts (NaCl, NaBr and MgCl2) and the water absorption from the subjective surface of the filter paper was recorded. The water vapour pressure of the desiccative LiCl-glycerine mixture was found as low as about 3 mmHg and that of the subject surface depended on the sort of salt solution used and its temperature, the
value of which being obtained from a table using filter paper temperature actually measured. In experiments using various salt solutions at various temperatures, the vapour pressure difference ($\Delta p$) between the desiccative mixture and the subject surface was calculated and the relationship between $\Delta p$ and water absorption rate (weight increase of the desiccant material) was obtained as is demonstrated in Fig. 7. Changes of electrical conductance of the desiccant material was registered in differential values at various $\Delta p$, giving finally the relationship between recorder deflections and rate of water absorption, as is shown in Fig. 8.

3. Examples of experiments on the human body.

Fig. 9 is an example of gravimetric method for demonstration of the relationship between vasomotor and sudomotor responses evoked by body heating. Upper trace is for heat conductivity of the skin which was recorded for demonstration of cutaneous vascular responses. The detailed description of the apparatus for thermal conductivity was omitted in the present paper. Middle and lower traces are the rate of water evaporation of the skin. The middle recording is for differential values, the lower for integral values. In integral recordings initiation of sudoriferous response is expressed in changes of the gradient of the curve, in differential recordings, on the other hand, by
FIG. 9. Example for gravimetric method in human experiment. From upward arrow to downward arrow thermal stimulus was applied by immersing both legs in water bath of 44°C. Records in flexor side of forearm, see text.

FIG. 10. Example of automatic electrical conductance method in the same experiment as in FIG. 9. Lower curve is for skin temperature.
changes in the height of spike deflection. Fig. 10 is an example in the same sort of experiment of body heating for autonomic electrical conductance method.

DISCUSSIONS OF THE METHODS

1) Gravimetric method. The displacement of the light spot figure on the measure scale is exactly proportional to the weight increase of the desiccant material on the balance dish, namely, to the volume of water absorbed by the desiccant. This relationship was demonstrated in the previous paper4). Movement of light figure on the distant scale was traced manually by means of a sliding apparatus which made possible to convert the weight increase directly into changes of electrical resistance of one limb resistor of a bridge circuit, resulting changes of unbalanced potential of the bridge. In practice, the accuracy of the conversion depends upon the concerning manipulative technique. It is not very difficult for an experimenter to trace manually the light movement in its detail, though there exist minute vibrations of the light spot which are caused chiefly by pulsatory movements of the body.

The sensitivity of this method is satisfactorily high. For example, water evaporation in insensible perspiration in the forearm with a rate of 0.07 mg/12.6 cm². 20 sec. was large enough for registration by the present method, as one can see in Fig. 5.

The range of the volume of water which can be measured by this method was considerably large. In this method, about 80 mg of saturated LiCl-solution containing about 40 mg salt crystal powder was used as desiccant material. The water absorbing power of the desiccant remains unchanged so long as there exist traces of unsolved crystals in the solution. The quantitative linear relationship between the rate of water absorption and recorder deflections, whether they are integral or differential values, hold good in the range of water absorption to as much as about 30 mg.

The unfavorable point of this method is that the method involves manual procedures. Further, as this is a gravimetric method using a micro-balance, the absorption capsule must be held horizontally on a stable table during experiments. The latter disadvantage restricts the utilization of this method to only a few particular body regions, for example, palm or forearm.

2) Electrical conductance method. The above disadvantages are kept out of this method as in this method water evaporation from the skin is recorded autonomically and the apparatus can be applied to any desired region of the body. On the other hand, however, this method contains some troublesome problems in the viewpoint of measuring principle. One of them is the effect of temperature which varies greatly the electrical conductance of the desiccative solution. There are various factors which cause tempera-
ture changes of the desiccant material during experiments. The problem of temperature is made more complicated by the fact that desiccative LiCl-glycerine mixture is a system which generates a large amount of heat when it absorbs water. Nevertheless, the present method is arranged to register changes of electrical conductance for each 20 seconds in series, a span of time during which the temperature change must be very small. The heat absorption cap C in Fig. 6 was applied, and this cap serves for cushioning of temperature changes of the desiccant mixture. Influence of temperature upon differential values of the conductivity was thus decreased to great extent, though its complete avoidance was very difficult.

Another unfavorable point of the method is that the saturation of electrical conductance of the desiccant system is reached even with a fairly small amount of water absorbed. In the present method, the volume of LiCl-glycerine mixture spread over filter paper for each application was about 0.8 gram, for this volume of mixture about 10-12 mg water was found to be the limit volume over which quantitative relation between absorption rate and change of conductivity is no more available. From this reason, the method is not suitable for recording of vigorous sweat secretion for long period.

The sensitivity of this method is demonstrated in Fig. 8. The rates of evaporation lower than about 0.5 mg./12.6 cm². min. could not be registered with certainty. So, for example, the rate of insensible perspiration in forearm, the value of which was found to be about 0.2-0.3 mg/12.6 cm². min., could not be recorded virtually by this method. The linear relationship between the evaporation rate and the recorder deflection was obtained, but the variance of the data was considerably large. The reason for it was considered to be attributable chiefly to the fact that it was difficult to paint the desiccant material on filter paper with absolute equality. In the experiment during which the desiccant paper was not changed and serial recordings were made for varying evaporation rate, the variance was found to be much smaller.

SUMMARY

Methods for continuous recording of cutaneous perspiration in a small area of the skin were reported. In the methods, desiccant material provided in an absorption capsule absorbs water vapour from the skin covered with the capsule. The volume of water absorbed in the desiccant was recorded as the increase of weight (gravimetric method) or as the increase of electrical conductance (electrical conductance method) of the desiccant material. In the gravimetric method, the weight increase was converted into movement of light spot on a distant scale, and finally, by means of manual procedure using a sliding apparatus, into unbalanced potential of a bridge circuit. In both methods, the changes of electrical measures were registered directly (integral
values) or as differential values using a device for differentiation circuit. Differential values were obtained as spike deflections, height of which represents the rate of water evaporation in 20 seconds. Examples of the results of application on human body were demonstrated for both methods.

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