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THE PHYSICAL AND CHEMICAL PROPERTIES OF HUMAN SWEAT AND FACTORS AFFECTING THE WATER BALANCE IN CONFINED SPACES

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SECTION I PERSONNEL

Table I.1. lists all persons who worked under this grant during the period 1 January 1966 - 30 June 1966, including several whose salaries were not paid from the grant, but by the University of Illinois.

TABLE I.1. PERSONNEL ASSOCIATED WITH NASA GRANT NGR 14-005-050. 1 JANUARY - 30 JUNE 1966

Name and Title*	Period of Association	Percentage of Salary Paid from this Grant
R. E. Johnson, Professor	1 January-- 30 June 1966	0
F. Sargent, II, Professor	1 January-- 30 June 1966	0
Mrs. Frances Robbins Biochemical Technologist	1 January-- 30 June 1966	0
T. Morimoto Research Associate	1 January-- 30 June 1966	100
Mrs. Keun Shil Shin Research Assistant	1 January-- 14 June 1966	100
B. Blase Graduate Assistant	1 January-- 14 June 1966	0
Mrs. Susan Kinney Clerk-Typist	1 January-- 17 April 1966	25
Mrs. Hazel Roosevelt Clerk-Typist	18 April-- 30 June 1966	25
Melinda Brookens Research Assistant	12 March-- 17 June 1966	100
Janet Harris Graduate Assistant	15 June-- 30 June 1966	100

Table I.1. (Continued)

Name and Title*	Period of Association	Percentage of Salary Paid from this Grant
Diane Wakat Graduate Assistant	15 June-- 30 June 1966	100
Paul Molé Graduate Assistant	15 June-- 30 June 1966	100
William Kachadorian Graduate Assistant	15 June-- 30 June 1966	25
Joseph Nelson Graduate Assistant	15 June-- 30 June 1966	25
Georgiana Benner Research Assistant	15 June-- 30 June 1966	100
Jackie Davis Laboratory Attendant	15 June-- 30 June 1966	100

*In addition to those listed, there were research subjects who worked from time to time as needed. These included: S. Berger, F. Blase, J. Bodammer, K. Leoni, U. Mazumdar, J. Miliszkiewicz, P. Molé, J. Nommensen, C. Trayser, and C. Tenczar.

SECTION II RESEARCH AIMS

Two major questions were asked. First, can the freezing point of eccrine sweat be accounted for in terms of the commonly measured substances urea, ammonia, lactate, chloride, sodium, and potassium? The answer to this question is fundamental to our understanding of the sweat gland's processes of excretion and secretion. Second, what is the viscosity of sweat? The answer to this question is of importance, because no reports have ever been published on this physical property of sweat. Clearly the

wetting properties of sweat are related in part to viscosity, and the wetting properties are important in the evaporation of water from the skin.

Three primarily methodological studies were started. The first has to do with appropriate methods for collecting and processing sweat, and the second with the acid-base properties of sweat, and the last with the secretory pressure of individual sweat glands.

SECTION III COLLECTION AND PROCESSING OF SWEAT

Among the many gaps in our knowledge of sweat are two that have importance in all studies involving that body fluid. The first is how the sweat should be collected. How should the skin be treated beforehand? What precautions need be taken against hidromeiosis if a vapor impermeable barrier is used to make the glove for collection? The second problem is how to handle the sweat after collection in preparation for analysis. What effect, if any, does a small amount of turbidity have on results? Should sweat be filtered, centrifuged, or both? In the comprehensive article by Robinson and Robinson (1958) little if any attention was paid to these fundamentally important considerations.

For this study we have tried to control the treatment of the skin beforehand, and we have standardized the processing of the sweat prior to analysis. The details follow for a "full-scale" experiment. Frequently, respiratory metabolism is not included, and collection of total body sweat is not done.

I. Preparations

A. Subject

1. The subject comes to the Human Environmental Unit the day before the experiment around 5 p.m., and stays until the experiment is completed. A standard evening meal is provided and should be eaten no earlier than 6 p.m. and no later than 8 p.m. Before bedtime both forearms are shaved with an electric razor, the fingernails cut closely and the arms scrubbed for 1 minute with a surgical brush and Vel (Colgate-Palmolive Company, N.Y.). The subject should go to bed not later than 11 p.m.

2. On the day of the experiment, the subject:

   a. Rises at 7 a.m. and takes care of personal needs. The time of voiding is noted to the nearest minute.
   b. Drinks 250 ml of water, but eats no food.
   c. Takes a hot shower using Vel.
   d. Puts on suitable clothing as prescribed and rests on the bed in the examining room from 7:30 to 8:00 a.m.

B. Arm bag, cotton pajamas, plastic pool, and towel

1. An impermeable arm bag (Wet dressing Bunyan bag. National Carbon Company, N.Y.) is used for collecting sweat.

2. Prior to the experiment the arm bag, pajamas, pool and towel are washed three times with tap water, twice with distilled water, and then air dried.

II. Collection of sweat, gas samples, and physiological data

A. Resting measurements

1. After 15 minutes of resting, begin flushing Tissot tank with expired air. Flush three times.

2. After flushing Tissot tank collect 10-minute sample of expired air. Mix with stirring motor and record gas temperature and station-level barometric pressure.

3. Remove counter-weight from Tissot tank meter stick. Open sampling valve and let expired air discharge by gravity.

4. Fill two previously evacuated gas sampling bags with samples of expired air.

5. After collection of expired air, measure blood pressure, pulse rate (one-minute count) and oral temperature.

B. Hot-room walk

1. Subject arises and walks leisurely to controlled

temperature hot room. Collect urine, noting time to the nearest minute.

2. Drink 250 ml of water maintained at about 35°C.

3. Start walking on treadmill at a pace of 5.8 km per hour.

4. After 10 minutes of walking, get off the treadmill, take off clothing and shoes. Dry the subject, and weigh him on a platform scale. Note time to the nearest minute.

5. Subject should soak both arms in distilled water for one minute, using a plastic cylinder. Blot off water with the towel which has been boiled in distilled water for 5 minutes, rinsed once in distilled water, and dried in air.

6. Apply bandages of about 5 cm width immediately above the elbow joints, and attach arm bags with bands. A "blank bag" will be prepared with 50 ml H_2O, and attached to the subject's belt.

7. The subject then walks for 60 minutes on a level treadmill at 5.8 km per hour with 5-minute rest after each 15 minutes of walking.

8. Every 20 minutes remove the glove and pour out the sweat into a measuring cylinder and record the volumn. Store the sweat in refrigerator in a brown bottle until the end of sweat collections.

9. Pour out the "blank bag" after the third walk period. Treat the blank exactly like sweat through all stages of preparation.

10. During 1st and 3rd walk, collect gas sample with the Kofrányi-Michaelis respirometer and later analyze for O_2 and CO_2.

11. During the 5 minute rests, measure and record the oral temperature, skin temperature at lateral side of right thigh, pulse rate and ambient dry and wet bulb temperatures. Criteria for early termination of

exposure to heat are:

a. Rectal temperature of 103°F or more
b. Pulse rate in excess of 130 per minute or more
c. Heat syncope
d. Exhaustion
e. Unusual symptoms

C. After the experiment, the subject lies down in a cool room for 15 minutes. Then he may take a shower, eat breakfast and leave, as long as he has no difficulties subjectively or objectively.

III. Processing of Arm Bag Sweat and Total Body Sweat

A. Arm bag sweat

1. (a) Mix the three arm sweat samples together and centrifuge at 2°C for 15 minutes at 3,000 rpm.
(b) Store in deep freeze at -20°C over night, and centrifuge again just after thawing the sample.
(c) If the sweat is not clear, repeat step (b) until the sweat becomes clear, and then divide the supernatant into six vials. Keep in deep freeze at -20°C prior to chemical analysis. Water blanks are to be treated exactly as the sweat sample.

B. Total body sweat

1. (a) After the three 20-minute periods, take off the sweat bag, clothing and shoes. The subject should be dried thoroughly with clean towels and weighed.
(b) Collect urine, noting time to the nearest minute.
(c) The subject should be transferred to a cool room. Wash down his body with 3 liters of distilled water into vinyl pool together with clothing and towel used during sweat collection. Then rinse the body with another 2 liters of distilled water. Mix the water thoroughly and take out 50-ml portions of the water for analyses. (d) Blank sample of 5 liters of of water should be added to the pool and 50-ml blank be taken from the pool just before the subject starts to use it.

2. The sweat is processed for analysis like arm bag sweat in Section III A 1 above.

C. Handling of sweat prior to analysis

1. The vials of sweat are kept frozen in wooden blocks at -20°C until needed for analysis.

2. The vials are taken from the wooden block and set individually in plastic cups on a table at room temperature (about 22°C).

3. Every fifteen minutes they are tipped from side to side. When the last ice has disappeared, the fluid sweat is examined for turbidity.

4. If the specimen is clear, the contents of the vial are mixed thoroughly, and the aliquot is taken for analysis, and the vial is placed in the refrigerator at 4°C.

5. If the specimen has any turbidity it is transferred to a cone tipped centrifuge tube, centrifuged in the angle-head centrifuge for 10 minutes, and the supernatant transferred by pipette or syringe into a clean vial. It may then be used for analysis.

6. When no longer needed for a series of analyses, the vial is retaped, placed in a wooden block, and refrozen.

D. Analytical methods used

References to the analytical methods that are used in this investigation are listed in Table III.1.

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TABLE III.1. CHEMICAL AND PHYSICAL METHODS FOR STUDYING THE COMPOSITION OF HUMAN SWEAT. (NASA GRANT NGR-14-005-050)

Substance	Authors	Type of Method
Total Nitrogen	Koch and McMeekin, 1924; Davenport, 1926	Acid digestion, nesslerization, colorimetry
Urea Nitrogen	Van Slyke and Cullen, 1914	Urease, aeration, nesslerization, colorimetry
Ammonia Nitrogen	Van Slyke and Cullen, 1914	Aeration, nesslerization, colorimetry
Na, K	White, 1952; Baird Assoc., 1953	Flame photometry
Chloride	Cotlove, Trantham, and Bowman, 1958; Am. Inst. Co., 1960	Aminco-Cotlove titrator
Osmolarity	Wesson, 1952; Fiske Assoc., 1954	Freezing point (Fiske osmometer)
Lactic Acid	Hawk, Oser, and Summerson, 1951	Copper liming, colorimetry
Ca, Mg	Kovács and Tárnoky, 1959, also Evans, Ltd., 1966	Chelation, titration; Atomic absorption spectrophotometry
Viscosity	Fenske and Cannon, 1952	Capillary tube
Density	Fenske and Cannon, 1952	Pycnometer
Total CO_2 and HCO_3	Consolazio, Johnson, and Pecora, 1963	Manometry
Sulfate	Bertolacini and Barney, 1957	Barium chloranilate colorimetry
pH	Clark, 1928; Bates 1954	Glass electrode
Freeze drying	Hansen and Robbins, 1956	Vacuum plus solid CO_2 freezing
Collection and processing	Robinson and Robinson, 1958	Several techniques

SECTION IV CHEMICAL COMPOSITION OF HUMAN ECCRINE SWEAT COMPARED WITH OSMOTIC PRESSURE

(Prepared for Publication in the Journal of Physiology)

Adams, Johnson and Sargent (1958) calculated the osmotic pressure of sweat from the freezing point, and compared this with the sum of important constituents, i.e. sodium, chloride, lactate, urea, potassium and ammonia. In about 200 of 600 specimens of sweat from young men the osmotic pressure calculated from the freezing point was higher than that calculated by adding together the constituents. This finding of Adams *et al*. (1958) was disputed by Foster (1961). He was able to account for 92% of the osmotic pressure in his specimens by measuring the osmotic pressure of a synthetic sweat which was prepared by adding up the measured constituents.

Experiments were performed seeking for explanations for this discrepancy between the British and American laboratories.

Methods

Collection of sweat

Thirty-three samples of sweat from 9 male and 2 female healthy student volunteers were analyzed. Sweat was collected between January 22 and May 19, 1966 under unacclimatized conditions with two exceptions. Intervals of one week or more were allowed between sweat collections from each subject, except for one subject (E.B.) from whom two specimens were collected before and after acclimation respectively. To acclimate to the hot environment, the subject walked on the treadmill at the same speed and under the same conditions for ten consecutive days. For chemical analyses, sweat samples from 1st day (not acclimated), 5th and 10th day (acclimated) were used. The samples of sweat collected on days 1, 2, 3, 6, 7, 8, and 9 were used for validating methods. One day before each experiment, the subject cut his finger nails and shaved both arms with an electric razor. Then the subject scrubbed both arms for 3 minutes using a surgical brush and a solid detergent (Vel®,Colgate-Palmolive, N.Y.) which is neutral in reaction and non-allergenic. Before an experiment the subject washed both arms for 3 minutes with the detergent and tap water, and rinsed thoroughly with running tap water. Then the subject entered the hot room (DBT: 40°C; WBT: 21°C; RH: 30%) and after 15 minutes of walking on a treadmill at the speed of 5.6 km/hr for males and 4.8 km/hr for females, rinsed both arms in a cylinder containing demineralized water. The arm

was then dried with clean towels that had been boiled 30 minutes in demineralized water and oven dried. Vinyl plastic arm bags (Wet dressing Bunyan bag for the arm: National Carbon Co., New York) were donned to the elbow and held in place by elastic bands 5 cm in width. The subject then walked on the treadmill for 80 minutes. Every 15 minutes a stop of 5 minutes was made to drain off sweat and to control the conditions of subjects. The arm bag used was not completely impermeable to water, the evaporative loss of water from inside being at the rate of 1% per hour under our experimental conditions. However, when the sweat samples were drained every 20 minutes, the loss was neglibible. Drinking water at a temperature near 35°C was allowed ad libitum. The volume of sweat was measured in calibrated cylinders. The samples were centrifuged at 3,000 RPM for 15 minutes at 25°C and if the supernatant fluid was clear decanted into vials, sealed with masking tape and refrigerated. If not used on the day of the sweat collection, they were frozen at -20°C until needed. In case the supernatant was not clear it was kept frozen overnight and centrifuged just after thawing. The turbidity of sweat samples is sometimes impossible to remove by ordinary centrifugation or filtration. The present technique does remove turbidity.

In each experiment, the subject wore at the belt a blank glove containing 50 ml of distilled water. This blank was treated exactly like sweat and samples were carried through all procedures, so that appropriate blank correction could be made if needed.

Analyses

Chemical analyses were performed within two days after clear sweat was obtained. The following methods were used:
1) sodium and potassium by flame photometry with an internal standard of lithium; 2) chloride by the Aminco-Cotlove titrator; 3) lactic acid by colorimetry after copper-liming (Hawk, Oser and Summerson, 1951); 4) total nitrogen by nesslerization following acid digestion (Koch and McMeekin, 1924); 5) ammonia nitrogen by nesslerization after aeration (Van Slyke and Cullen, 1914), 6) urea nitrogen by a urease method (Van Slyke and Cullen, 1914); 7) Ca and Mg by atomic absorption spectrometry or by a colorimetric method (Kóvacs and Tárnoky, 1959); 8) amino acids by a Beckman amino acid analyzer.

The pH of sweat samples was measured at 25°C with a Beckman Expandomatic pH meter with phthalate buffer (4.01) and phosphate buffer (6.86) as standards.

A Fiske thermistor osmometer was used to measure the freezing point of sweat samples. Aqueous solutions of NaCl ranging from 0 to 0.5 molar were used as standards under the assumption that molarity is practically equal to molality at this range of concentration. For the purpose of conversion from molarity to osmolarity, corrections for NaCl standard were made as indicated by the Fiske Osmometer Instruction manual (Fiske Associates, Inc., 1954). These factors are based on the International Critical Tables (1938).

Results and discussion

The results are summarized in Table IV. 1. and IV. 2. A striking point is large individual variations. As obvious from standard deviations, for mean of each subject and for total mean, interindividual variations are greater than intraindividual variations for sweat rate, all measured constituents of sweat, pH, and for osmolarity.

Osmolarity and sweat constituents

The relation between sweat osmolarity and sum of main sweat components is shown in Figure IV. 1. which shows that sum of sweat components is lower than measured osmolarity by 5% of osmolarity. When "osmotic deficit" is defined as the deviation between measured osmolarity and sum of main solutes, and expressed as per cent of total osmolarity, the deficit ranges from -5.4% to 11.9%. Here again, some subjects show consistently low osmotic deficits, while some other subjects show high osmotic deficits. According to Foster, the osmotic deficit calculated in our way for his subject group was almost 0%. Adams et al. (1958) found that the deficit for one group was 6% and for the other group 13%. In considering this discrepancy, the following factors should be taken into account.

Individual idiosyncrasies in chemical components of sweat

From the fact that some subjects show consistently high osmotic deficit and some other subjects show consistently low deficit, it could be well supposed that the contribution of unmeasured sweat constituents to sweat osmolarity might differ greatly from subject to subject. To test this assumption, Ca and Mg in sweat were measured with results shown in Figure IV. 2. These two components showed higher values at low rate of sweating than at high rate of sweating. Although there is big individual

variation (Sargent, Morimoto, and Ohara, 1966), sodium and chloride contents in sweat generally increase as sweat rate increases (Kuno, 1956). On the other hand Ca and Mg concentrations decrease as sweat rate increases, together with potassium, lactate and ammonia. According to Sargent et al. (1966), four types of individuality can be identified from sweat rate and chloride content in sweat, i.e. i) high sweat rate and high chloride, ii) high sweat rate and low chloride, iii) low sweat rate and high chloride, and iv) low sweat rate and low chloride. The contribution of unmeasured constituent to osmotic deficit must be larger in groups iv) and iii), which have a low sweat rate.

Osmotic coefficients.

In this present paper and the paper of Adams et al., (1958) correction for NaCl standard solutions for osmotic coefficients was based on The International Central Tables. Foster (1961) used values by Robinson & Stokes (1959). Slight differences in osmotic coefficients can cause differences in osmolarity, which might be measurable. For example the osmotic coefficient of 0.2 molal NaCl solution is given by Robinson et al. (1959) as 0.9245, while Fiske's standard gives the value of 0.936. The deviation caused by this difference is about 2.2 mOsm/l at the molality of 0.2. In other words, Foster's calculations on osmolality measurements are about 2% lower than our results. This accounts for some of the deviation between his and our results; but by no means all.

Another point of some interest is that there is no evidence that the osmotic coefficient of sodium in sweat is equal with that of sodium chloride standard solutions. Therefore activity coefficients of Na+ ion in sweat were calculated from Na^+ concentrations measured by flame-photometry and Na^+ activity measured by Na^+ sensitive glass electrode. A sweat sample (Na: 38 mEq/L; K: 6.1 mEq/L; NH_4: 3.9 mEq/L; Cl: 30.0 mEq/L lactate: 12.3 mM/L; Urea: 8.4 mM/L) was used for this purpose and divided into three parts. NaCl was added to two parts of the sweat to make up the Na^+ concentrations of about 50 and 100 mEq/l. On the other hand, four NaCl standard solutions were made up with four different NaCl concentrations (25 to 150 mEq per L) and 6.1 mEq per L of KCl; this was the concentration of K in the sweat sample used for this purpose. Activities for Na^+ ion in the standard solutions were calculated from activity

coefficients derived from Debye-Hückel formula* (Robinson & Stokes, 1959). With the standard solutions, Na^+ activity-E.M.F. calibration curves were obtained using Na^+ ion sensitive glass electrodes by Beckman. As shown in Table IV. 3 for sweat the Na^+ion shows higher activity than in simple solutions of NaCl and in solutions more dilute than 0.05 mEq/L, the activity of Na^+ ion becomes almost equal to Na^+ concentration. From these data, it might well be assumed that osmotic coefficients of sweat at the freezing point are higher than that of sodium chloride standards. If this is the case, the osmolarity of sweat calculated from the freezing point must be higher than the true osmolarity.

$$* \log f = - \frac{A|Z_1 Z_2|\sqrt{I}}{1+Ba\sqrt{I}} + bI, \quad I = \tfrac{1}{2}\sum (C_i Z_i^2)$$

f:	activity coefficient	for constants the following values were used
I:	ionic strength	
C:	molality	A= 0.5115 B= 0.3291×10^8
Z:	Valency	a: 4.00Å b: 0.055

The validity of this formula for biological solutions was shown experimentaly by Yoshimura, Hirakawa and Morimoto (1962).

Other factors

After their experiments of 1957, Adams et al (1958) pooled their specimens of sweat and stored them in a deep freeze; we have now reexamined those specimens. There were three categories: low osmotic deficit, medium osmotic deficit, and high osmotic deficit. The samples of Adams et al (1958) were analyzed by us twice, once before and once after centrifugation. This was done to conform with our technique for preparing clear specimens. The results are summarized in Table IV. 4 together with the data from one of our subjects. Although the order of magnitude of the deficit was about the same as reported by Adams et al (1958), the deficits were reduced somewhat by centrifugation. The main difference between the "before" and "after" analyses was an increase

of Na concentration, which can, also, be observed in the sample of sweat from our collection. At first, we thought that the turbidity of sweat must be caused by fine skin debris which cannot be removed with only one centrifugation. In that case, the amount of total nitrogen should be reduced considerably after the second centrifugation. As shown in Table IV. 4, decreases in total N and osmolarity are small except in the sweat samples with high osmotic deficit, so, the turbidity should be attributed to some other chemicals which have a large molecular weight.

The fact that the turbidity was found occasionally in the water from the blank bag suggests that the high molecular substance is related to the polyvinyl in the arm bag. Another interesting observation on the samples from Adams et al. (1958) is that they show a brownish color. The sweat with high osmotic deficit shows the deepest color and that with medium osmotic deficit shows medium color and that with low osmotic deficit is almost clear. Spectrophotograms were taken on these three samples and on one of our samples and on sweat ten times concentrated by mean of freeze-drying (Hansen and Robbins, 1956). Although there is no appreciable peak of absorption band in the visible range, every sample measured shows a high absorption in the ultraviolet. We do not know what this pigment is or means.

Taking all these into account, the fact that Adams et al. (1958) found a high osomotic deficit from sweat samples which had a low sweat rate and a high osmolarity might be explained in terms of their "two sweat" hypothesis. If one kind of sweat gland produces a sweat of high osmolarity but increases its volume slowly, and another produces a sweat of low osmolarity but increases its volume rapidly, then at low total rates of sweating, the mixture of sweat from these two kinds of glands should have a high osmolarity. This should then fall off with an increasing rate of sweating.

An alternative hypothesis might be that non-sweat gland tissue contributes chemically to the sweat collected in an impermeable glove. In the sweat which has a low sweat rate, the portion of unmeasured constituents should be higher than the sweat secreted with high rate. If the treatments of skin before sweat collections or washing out of initial sweat is not adequate, the effects of substances dissolved out from skin tissue other than the sweat glands might contribute to the osmotic deficit especially at low rates of sweating. Because

the specimens of sweat used by Adams et al. (1958) were collected from completely acclimatized subjects, their salt contents were extremely low. From subject E.B. in our current experiments, sweat samples were collected before and after acclimation to heat. As shown in Table IV. 2, osmolarity of the sweat sample from this subject showed 198.8 mOsm/L and 130.4 mOsm/L before and after acclimation respectively. Osmotic deficits of 17.6 mOsm/L decreased to 12.3 mOsm/L after acclimation, but the percentages of the deficit to total osmolarity were 8.8 % and 9.5 %.

The discrepancy between Foster's (1961) conclusions and those of Adams et al. (1958), and these present findings cannot be explained. His own explanation has to do with differences in osmotic terminology and coefficients. When his own data are treated by our mathematical techniques, there is no osmotic deficit. In our laboratory there is such a deficit, large in some specimens. Differences in subjects, especially in their state of acclimation, differences in handling the sweat, differences in analyzing the sweat--any or all of these may play a part. At least we do not deny the validity of his observations, as he has of ours.

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Table IV. 1. Chemical Constituents and Acidity of Human Sweat. Spring 1966.
(NASA Grant NGR-14-005-050)

	Na mEq/1	K mEq/1	NH_3 mEq/1	Σ Cations mEq/1	Urea mM/1	N
Men						
E.B. I*	76.0	5.8	2.9	84.6	12.1	2
II**	46.0	5.6	2.1	53.6	19.1	2
J.B.	32.2 ± 1.7***	6.1 ± 0.7	3.8 ± 0.5	42.0 ± 1.8	9.1 ± 1.7	5
L.D.	61.2 ± 6.2	8.5 ± 1.4	3.0 ± 0.3	72.8 ± 7.2	10.6 ± 2.4	5
W.K.	55.0	7.8	2.4	65.3	7.9	1
J.M.	99.0	6.9	1.8	107.7	4.7	1
P.Ma.	57.0	7.7	2.7	67.4	8.6	1
P.Mo.	75.0	9.9	5.0	89.8	9.5	2
J.N.	113.8 ± 8.9	9.9 ± 0.7	3.4 ± 0.8	127.0 ± 9.6	8.6 ± 2.3	4
M.S.	53.6 ± 9.0	5.6 ± 0.4	3.2 ± 0.2	62.3 ± 9.1	12.3 ± 1.9	7
Women						
M.B.	70.0	6.2	1.6	77.8	6.2	2
C.T.	63.0	5.3	2.9	71.2	7.8	1
Total	63.8 ± 24.7	7.1 ± 1.9	3.1 ± 0.9	74.0 ± 25.9	10.4 ± 4.0	33

Table IV. 1. (Continued)

	Cl mEq/1	Lact. mEq/1	ΣAnions mEq/1	pH	N
Men					
E.B. I*	72.1	12.3	84.5	6.02	2
II**	43.3	9.7	52.9	6.88	2
J.B.	27.2 ± 2.2	15.1 ± 1.8	42.3 ± 2.7	4.88 ± 0.13	5
L.D.	52.3 ± 4.4	20.2 ± 2.1	72.5 ± 5.3	7.36 ± 0.35	5
W.K.	43.6	19.1	62.7	6.98	1
J.M.	91.1	14.8	105.9	7.71	1
P.Ma.	45.1	24.3	69.4	6.89	1
P.Mo.	67.5	23.7	91.1	6.39	2
J.N.	111.6 ± 10.0	19.4 ± 1.7	131.0 ± 11.0	6.61 ± 0.45	4
M.S.	47.4 ± 7.9	14.6 ± 1.0	62.0 ± 7.8	5.86 ± 0.67	7
Women					
M.B.	59.1	16.6	76.0	7.75	2
C.T.	62.0	10.6	72.6	6.91	1
Total	57.6 ± 25.3	16.6 ± 4.6	74.3 ± 26.9	6.40 ± 0.95	33

*Unacclimatized
**Acclimatized
***Mean ± S.D.

Table IV. 2. Sweat Rate, Osmolarity, Sum of Solutes, and Osmotic Deficit. Spring 1966. (NASA Grant NGR-14-005-050)

	N	Sweat Rate ml/hr	Osmolarity mOsm/1	Sum of Main Solutes mM/1	Osmotic Deficit mM/1	Osm. Deficit % of Osmolarity
Men						
E.B. I*	2	126	198.8	181.2	17.6	8.75
II**	2	147	130.4	118.2	12.3	9.48
J.B.	5	103 ± 22***	95.7 ± 7.0	93.4 ± 4.5	2.2 ± 3.0	2.13 ± 2.92
L.D.	5	41 ± 2	165.4 ± 13.0	156.1 ± 12.0	9.3 ± 4.0	5.60 ± 2.23
W.K.	1	48	136.3	135.9	0.4	0.29
J.M.	1	156	219.4	218.3	1.1	0.50
P.Ma.	1	33	150.5	145.4	5.1	3.38
P.Mo.	2	30	202.1	190.4	11.8	6.27
J.N.	4	42 ± 11	285.1 ± 15.8	266.5 ± 19.2	18.6 ± 6.5	6.60 ± 2.58
M.S.	7	76 ± 9	137.4 ± 13.2	136.8 ± 16.3	0.6 ± 4.8	0.62 ± 3.54
Women						
M.B.	2	26	166.1	159.9	6.2	3.80
C.T.	1	24	170.7	151.6	19.1	11.18
Total	33	71 ± 39	166.0 ± 56.3	158.2 ± 52.0	7.8 ± 8.0	4.28 ± 4.13

*Unacclimatized
**Acclimatized
***Mean ± S.D.

Table IV. 3. Concentration, Activity, and Activity Coefficient of Sodium Ion in Sweat. Spring 1966. (NASA Grant NGR-14-005-050)

Sample	(Na^+) by flame-photometry mEq/1	(Na^+) at 25°C by glass electrode mEq/1	f_{Na^+} at 25°C experimental	calculated
No. 1	38	38	1.000	0.822
No. 2	53	53	1.000	0.806
No. 3	104	92	0.884	0.770

Table IV. 4. Centrifugation of Sweat and its Effects on Chemical Composition and Osmolarity. Spring 1966. (NASA Grant NGR-14-005-050)

Sample	low Osmotic deficit			medium Osmotic deficit			high Osmotic deficit			Subject W.K.		
	I	II	Δ	I	II	Δ	I	II	Δ	I	II	Δ
pH	8.15	8.09	-0.06	7.80	7.85	-0.05	8.04	8.04	± 0	6.98	6.98	± 0
Na	15.0	17.0	+2.0	29.0	31.0	+3.0	35.0	38.0	+3.0	51.0	55.0	+4.0
K	3.5	3.5	± 0	5.6	5.5	-0.1	12.9	13.1	+0.2	7.4	7.8	+0.4
NH_3	3.5	4.2	+0.7	4.6	4.8	+0.2	14.7	14.6	-0.1	2.3	2.4	+0.1
Cl	12.5	13.2	+0.7	25.8	26.1	+0.3	30.1	29.9	-0.2	44.1	43.6	-0.5
Lact.	8.3	8.5	+0.2	11.3	11.5	+0.2	26.5	25.7	-0.8	19.3	19.1	-0.2
Urea	5.8	5.9	+0.1	7.9	9.6	+2.3	20.9	19.3	-1.6	7.5	7.9	+0.4
Total N.	19.3	18.9	-0.4	27.1	26.8	-0.3	77.1	75.7	-1.4	33.9	33.5	-0.4
Σ Solute	48.6	52.3	+3.7	84.2	88.5	+4.3	140.1	140.6	+0.5	131.6	135.9	+4.3
Osmolarity	51.4	51.6	+0.2	89.8	88.8	-1.0	156.1	152.6	-3.5	136.0	136.3	+0.3
Osmotic def.	2.8	-0.7	-3.5	5.6	0.3	-5.3	16.1	12.0	-4.1	4.4	0.4	-4.0
%	5.4	-1.3		6.2	0.3		10.3	7.6		3.2	0.3	

First three samples are the sweat from Adams _et al_ (1958). The last sweat is from our own collection. Columns I, II, and Δ represent results of analyses after one centrifugation, a second centrifugation and deviations between the two analyses.

Fig. IV.1

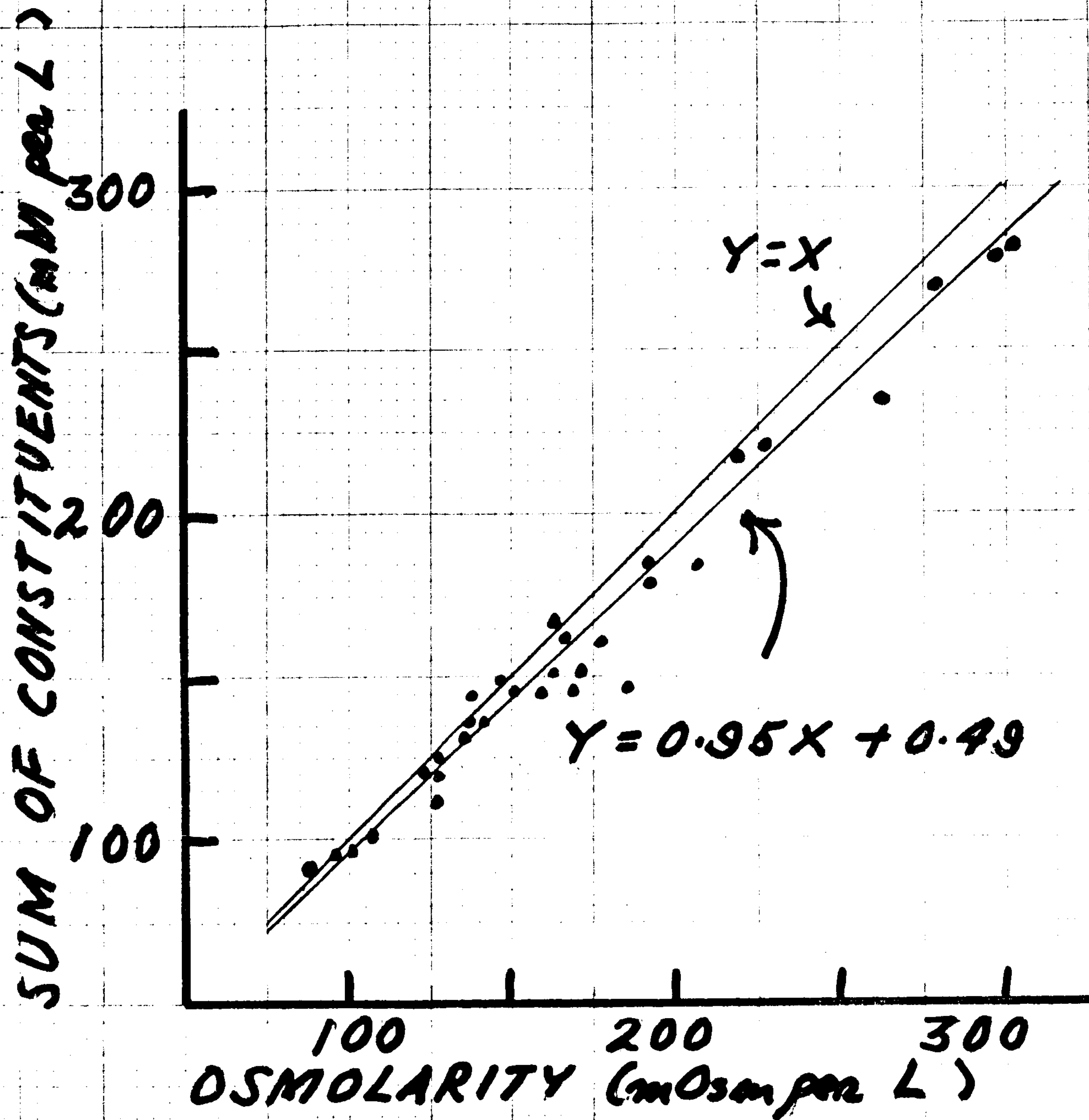

Figure IV. 1--The relationship between osmolarity (freezing point) and the sum of Na, K, NH_3, Cl, and lactate in sweat. The regression line was calculated by the method of least squares. It is compared with the theoretical line of no osmotic deficit.

SECTION V ACID-BASE PROPERTIES OF HUMAN SWEAT (Prepared for Publication in Science)

The acid-base balance of sweat has been little studied, and then rarely systematically or completely. In 1935, Whitehouse (9) wrote "the data published regarding the reaction of sweat do not show agreement in general, and sweat has been reported as acid, alkaline, and neutral by different authors." Since that time, methods of pH measurement have improved greatly but the situation still remains confused (cf. Rothman (7) and Kuno (5).)

As the buffer systems governing the pH of human sweat, the lactic acid - lactate system (1, 8), amino acids (7) and the bicarbonate system (3) have been claimed to be responsible. In this present study, correlations were sought between the acidity of sweat and its main chemical constituents.

Methods

Collection of sweat sample

Thirty-three sweat samples from 9 male and 2 female healthy student volunteers were analyzed. Sweat was collected and processed between January 22 and May 19, 1966. Details of collection, processing, and analysis have been given in Sections II, III and IV above.

Analyses

Chemical anaylses were performed within two days after clear sweat was obtained. For references see Table III. 1: 1) Sodium and potassium by flame photometry with an internal standard of lithium; 2) chloride by Aminco-Cotlove titrator; 3) lactic acid by copper-liming and colorimetry; 4) total nitrogen by nesslerization following acid digestion; 5) ammonia nitrogen by nesslerization after aeration; 6) urea nitrogen by a urease method, corrected for ammonia nitrogen; and 7) amino acids by a Beckman amino acid analyzer.

The pH of sweat samples was measured at 25°C with a Beckman Expandomatic pH meter with phthalate Buffer (4.01) and phosphate buffer (6.86) by Beckman as standards. At various stages of sample preparations, as just after sweat collections, after centrifugations and after melting the specimens, the pH of sweat samples was measured. There were no appreciable changes in processing.

Results and discussion

Observed pH values of sweat ranged from 4.70 to 7.99 with a mean value of 6.40. Individual variation of pH was considerable while sweat acidity for one subject was rather constant. Correlation coefficients were calculated between pH and the main chemical constituents or sweat rate which are shown in Table V. 1. The closest correlation (a negative one) was found with NH_3, especially its percentage of osmolarity, while other constituents and sweat rate had only poor correlations (Figs. V. 1, V. 2, and V. 3). The fact that the amount of NH_3 had a high correlation with acidity could be explained if NH_3 is assumed to be excreted in the form of NH_4Cl, as happens in the kidney (6). This assumption can very well explain the findings on sweat pH by other investigators, too. As sweating progresses, the acidity of sweat mostly decreases (4) because the amount of NH_4Cl also decreases. The higher the salt content, the less the acidity (4) because there are positive correlations between sweat rate and Na or Cl concentrations (5), and also because the concentration of NH_4Cl decreases as sweat rate increases.

The fact that high correlations between sweat rate or Na and Cl concentrations and pH were not found is important. As mentioned before, sweat pH from each subject showed rather constant values from collection to collection. On the other hand, the variances of pH values from one subject to another were remarkable. A similar situation could be seen for the sweat collected from the same individual at different stages of acclimatization. It is well known that as acclimatization to work progresses, the sweat rate increases while chemical constituents decrease (5). When sweat rates and pH values from the same subject or from the same stage of acclimatization were compared, there were correlations between the pH and sweat rate or Na and Cl, for example, the five points with lowest pH in Figure V. 3. are results from one subject. But when results from different individuals or from different stages of acclimatization were analyzed together, the correlation disappeared (Figs. V. 1, 2, and 3). There are some sweat constituents with which sweat pH has high correlations when analyzed on the basis of individual subjects but only poor correlations when a number of subjects are analyzed together. Those constituents have only secondary correlations. The constituent which has constantly a high correlation with pH, regardless of wide individual variations in sweat constituents must be the factor which determines the pH of sweat.

Lactate had only a poor correlation with pH, although it, like NH_3, decreases with increasing sweat rate. The lactic acid - lactate system has good buffering capacity at pH 4 - 5, but at pH 4.70 - 7.99, which was the range in our experiments, it cannot be considered a good buffer system. It would be excreted mostly as lactate and the amount of lactic acid must be very low at this pH range.

In our experiment, no attempt was made to handle the sweat specimens anaerobically, so that it is impossible to discuss the relationship between pH and CO_2 concentration in the actual sweat. Carbon dioxide dissociation curves for sweat (Fig. V. 4) were studied to detect a CO_2 combining capacity of sweat. The sweat has a slightly higher combining capacity than distilled water, which might be attributed to carbamino compounds. Still the magnitude is far less than that of blood and if CO_2 in sweat is transferred only by diffusion, the level of CO_2 must be less than 4.0 mM/l assuming Pco_2 of the tissues around sweat glands as 50 mmHg. According to Kawata (3), the total CO_2 concentration in sweat increases as sweat rate increases, ranging from a low of 0.8 to a high of 8.5 mM/l He stated that the HCO_3^- content in sweat has a high correlation (r=0.809) with sweat pH. He concluded that the major part of CO_2 in sweat is excreted as HCO_3^-, which seems reasonable because according to our data, diffusion can explain only up to 4.0 mM/l of CO_2.

Another factor which has been claimed to be related with acid-base balance in sweat is amino acids (7). Sixteen free amino acid contents were measured on one of our sweat samples (Table V. 2). The amino acid contents observed in this experiment are generally lower than that reported by Hier _et al_. (2), amounting to a total of 2.9 mM/l. The sweat sample was collected from an acclimatized subject. To study the effects of amino acids on the acid-base balance, titrations of sweat were performed and a titration curve from a sweat sample (I) and that of 10 times concentrated sweat (II) are shown in Fig. V. 5. From titration curve I, inflection points can be observed around pH 2.2, 10.5, and 11.6. In curve II, many points of inflection can be seen at lower pH than 4. Although it is impossible to identify exact inflection points or amino acids from these curves, these low pK's might be attributed to amino acids.

From these findings it is concluded that the acidity of sweat is determined mainly by the proportion of NH_4Cl to total chemical constituents. The lactate, bicarbonate, and amino acid buffer systems are of minor importance, but may modify the acidity to some extent.

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Table V. 1. Correlation Coefficients Between pH and Chemical Constituents. Spring 1966. (NASA Grant NGR-14-005-050)

Item	Correlation Coefficient with pH	
Sweat rate	-0.380	
	Concentration	% of Osmolarity
Na	0.457	0.257
Cl	0.400	0.374
NH_3	-0.563	-0.870
K	0.302	-0.469
Lactate	0.245	-0.439

Table V. 2. Amino Acids in Sweat. Spring 1966. (NASA Grant NGR-14-005-050)

Amino Acids	Concentration mM per L.	Amino Acids	Concentration mM per L.
Serine	0.75	Leucine	0.06
Alanine	0.48	Isoleucine	0.04
Glycine	0.41	Tyrosine	0.04
Threonine	0.14	Arginine	0.03
Histidine	0.14	Phenylalanine	0.03
Aspartic Acid	0.11	Proline	0.03
Valine	0.09	Methionine	0.01

12-282

FIG. V. 1

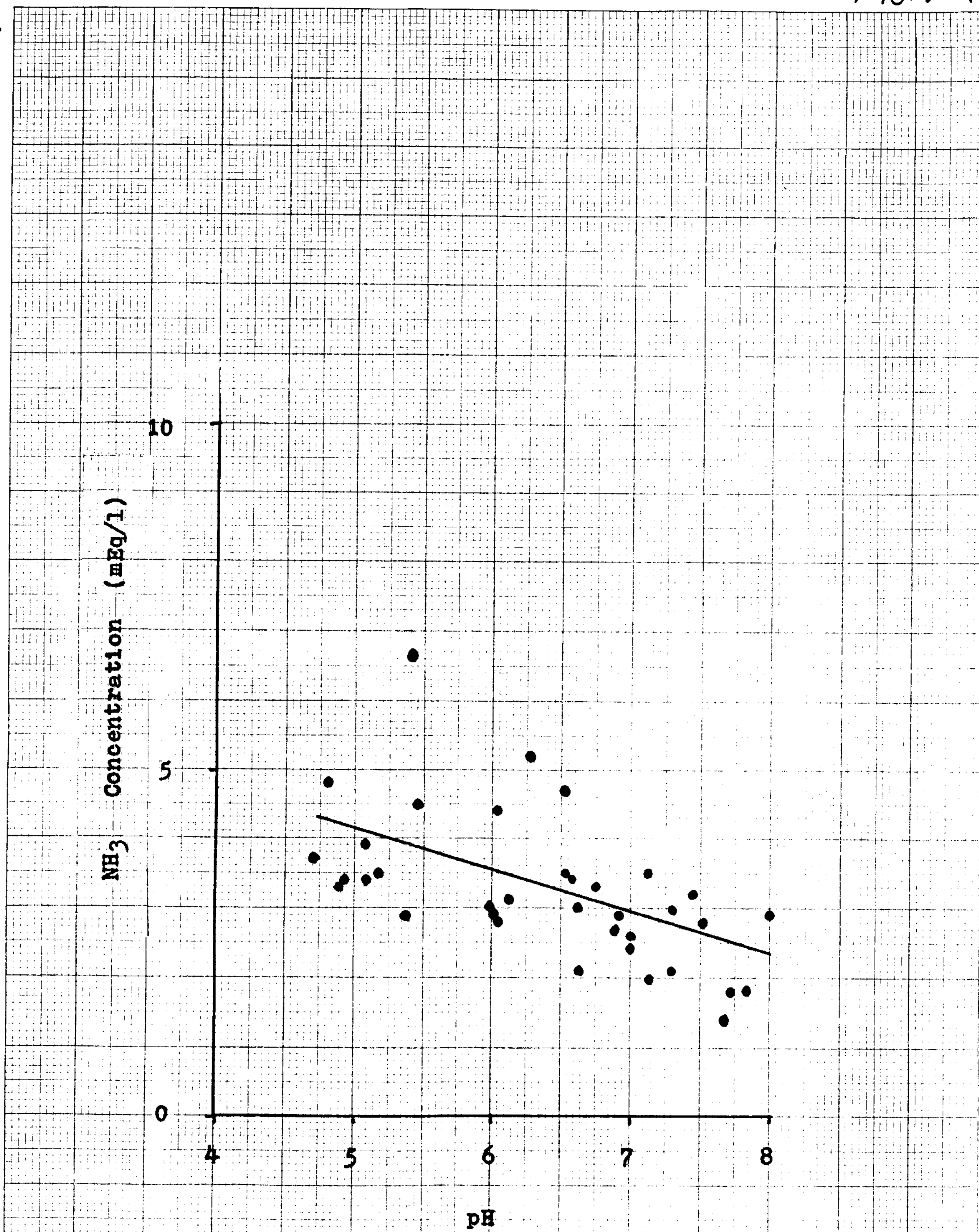

Figure V. 1. Relation between pH and ammonia concentration in sweat. By the method of least squares the regression equation is: Y = -0.59X + 7.1

20 Squares to the Inch

NATIONAL
12-282

FIG. V.2

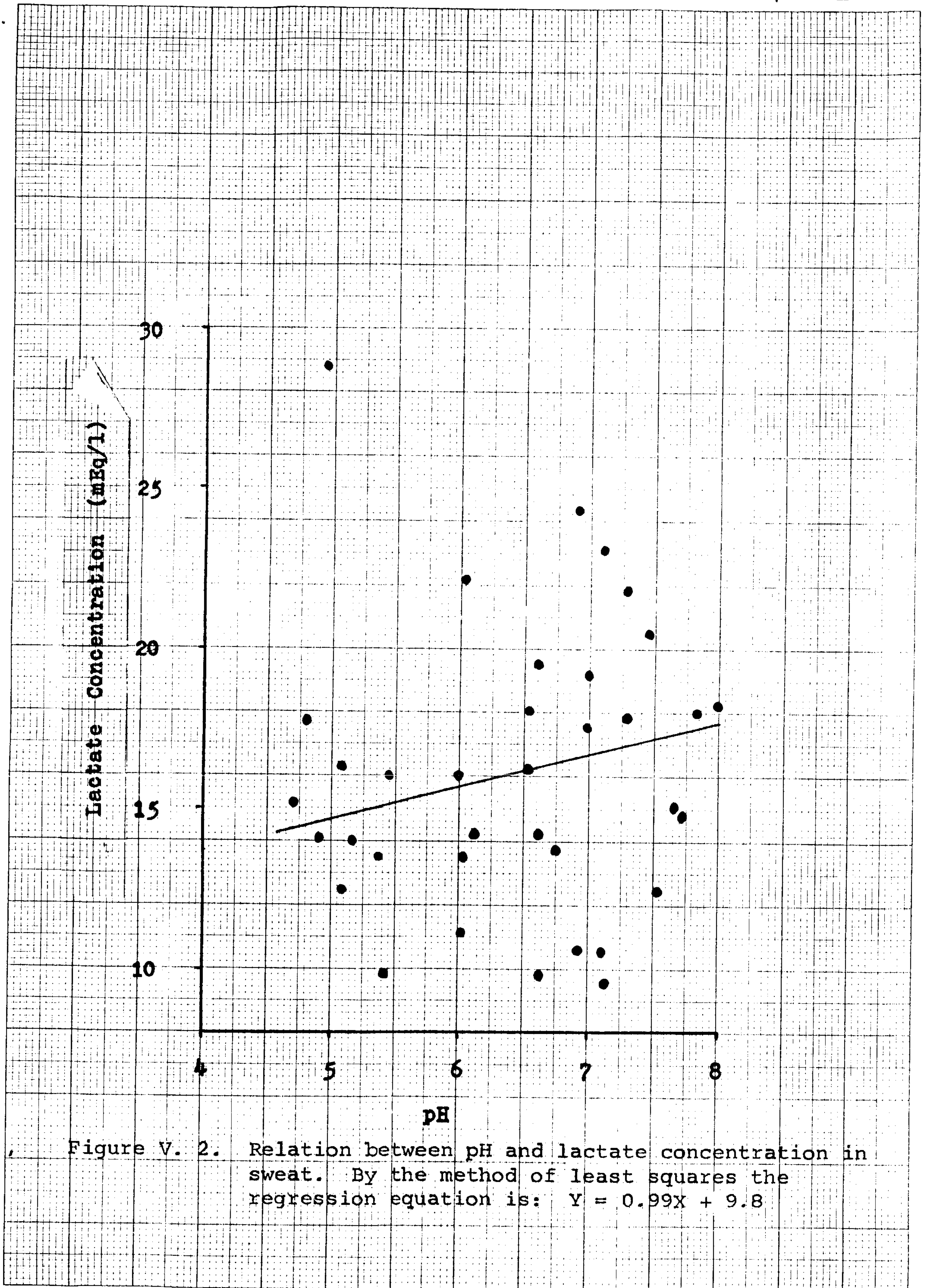

Figure V. 2. Relation between pH and lactate concentration in sweat. By the method of least squares the regression equation is: Y = 0.99X + 9.8

20 Squares to the Inch

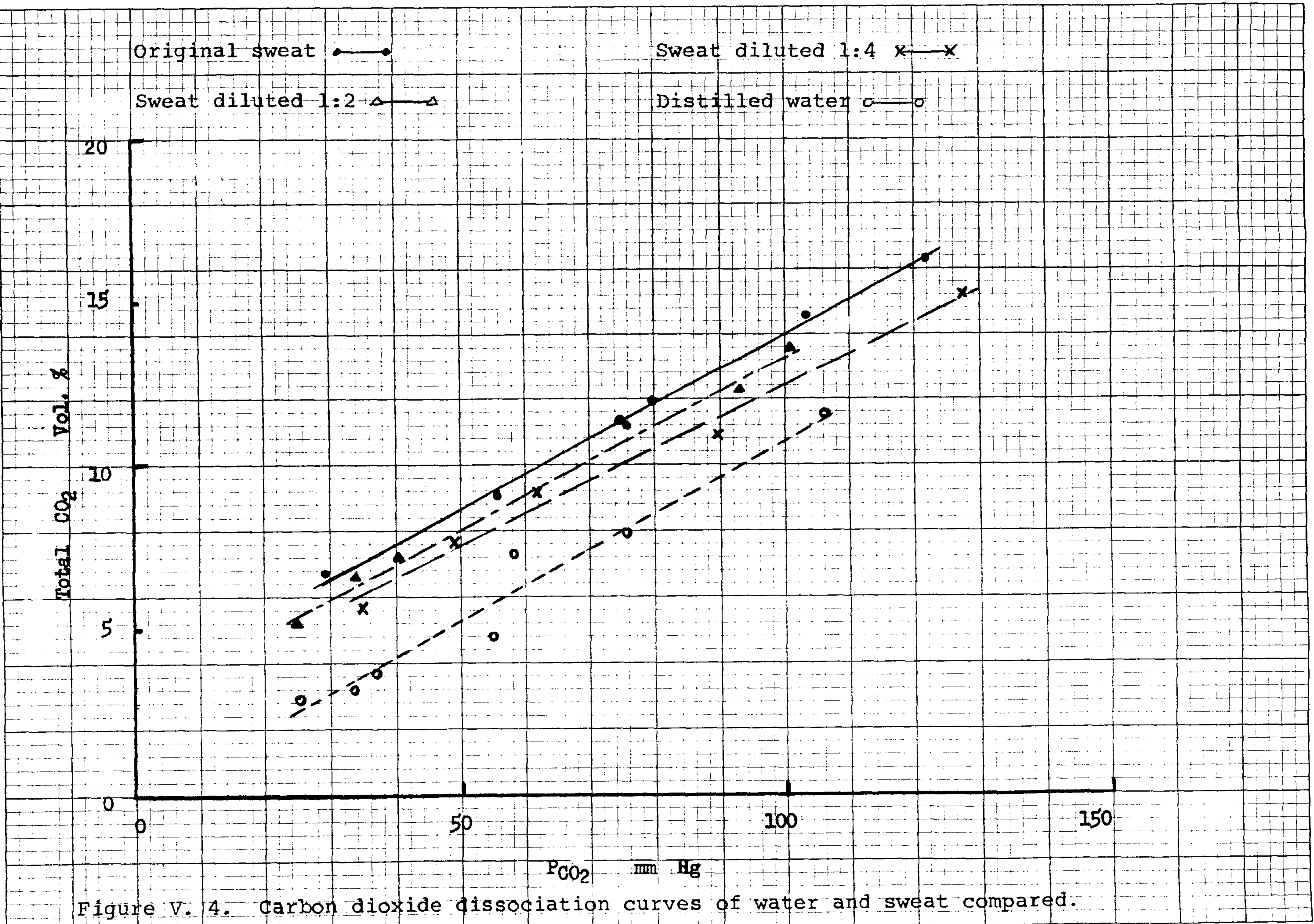

Figure V. 4. Carbon dioxide dissociation curves of water and sweat compared.

SECTION VI VISCOSITY AND DENSITY OF SWEAT
(Prepared for publication in the Journal of Applied Physiology)

Study of the physical properties of sweat has been neglected. For instance, a search of Chemical Abstracts from 1907-1966, Biological Abstracts from 1926 to 1966, and Index Medicus from 1953 to 1966 plus a search of major texts of physiology back to 1895 failed to reveal a single citation on the viscosity of human sweat. Of the few references to the density of human sweat (2, 7, 11, 15) none is recent. In view of the possible importance of these properties in relation to wetting of the skin, latent heat of vaporization, and other measurements important in calculating heat balance, this series of experiments was carried out on the viscosity and density of human eccrine sweat, and the temperature dependence of these properties.

Methods

The Cannon-Fenske modification of the Ostwald viscometer was used to measure viscosity (3, 18). This instrument requires a 5 ml. charge and is available commercially (No. 50 Kimax viscometer, Kimax Company, Owens, Illinois). Several authors have established the conditions for its accurate use (1, 5, 8).

Pycnometry was used to measure the density of the samples. This method consists of weighing a known volume of the sample. A 5 ml. pycnometer (E. H. Sargent and Company, Chicago, Illinois) was used and its volume accurately determined with triple distilled water (Barnstead Hospital Still) before each run.

Temperature control within $\pm 0.02^{o}C$ was achieved with a silvered 6 L. battery jar as a water bath and placing it in an environmentally controlled room where temperature was controlled to $\pm 0.5^{o}C$. The temperature of the bath was further controlled by means of a small external light which was used to warm the bath if the temperature dropped.

The viscometer was placed in the water bath and viewed through a small unsilvered portion in the wall of the battery jar. All materials (reagents, glassware, samples, etc.) were kept in a temperature controlled room at $24^{o}C$ to insure their being at the proper temperature. All equipment was cleaned with sodium triphosphate, followed by elaborate rinsing with distilled water. The sweat was collected in polyethylene arm bags (wet dressing Bunyan bag for the arm, National Carbon Company, Inc.

New York, N. Y.) from male university students walking on a level treadmill at a room temperature of 43°C dry bulb and 27°C wet bulb temperature. Sweat was collected at 30-minute intervals, the total sweat being the result of about 100 min. of walking. The sweat was frozen overnight at -20°C and the following day it was thawed and centrifuged at 3000 rpm for 10 min. This operation removed desquamated epithelial cells and other debris. The samples were refrozen and then thawed for analysis and examined for turbidity. If the sample was turbid it was centrifuged again and then used for analysis. Repeated measurements showed thawing and refreezing for periods up to a month had no effect on the density or viscosity of the sweat.

Results

Table VI. 1. presents the data for 11 samples of eccrine sweat. These determinations were made at 24.3°C. Each entry in the table is the average value of three determinations on that sample.

Table VI. 2. gives the data from the studies of temperature dependence. The values for water are from Hodgeman (9). Once again each value is the average of three determinations on that sample. In both tables the density values are within ±0.002% and the viscosity within ±0.02%, which are the limits of accuracy set by the respective methods.

Figure VI. 1. depicts the temperature dependence of the density and relative viscosity from the data of Table VI. 2.

Discussion

Solutions of sodium chloride were chosen as reference solutions because there is adequate data on their viscosity and density in the literature (10, 13, 16) and thus they could be used to determine the validity of the methods of measurement. Sodium chloride is also the major constituent of sweat and so a comparison of the data for sweat and for NaCl enables one to determine if sweat acts as a simple solution of NaCl.

With reference to Table VI. 1. we see that the viscosity and density of sweat are in all cases greater than that of water at the same temperature. Average values for the 11 samples are 1.00176 gm/ml for density, 0.9191 cp. for absolute viscosity and

1.0128 for relative viscosity. (Relative viscosity is defined as the absolute viscosity of the sample divided by the absolute viscosity of water at the same temperature.) A conversion of the average density into specific gravity gives 1.0046 which is in good agreement with the average from the literature (2, 7, 11, 15) of 1.004. There is a large variation of values between individuals and for the same individual at different times.

The data of Table VI. 2. show that both the time of fall and the absolute viscosity of sweat behave in a manner quite similar to that of water and the NaCl solutions. Both time of fall and absolute viscosity decrease in an almost linear fashion as the temperature increases.

If we consider the density of the sweat (Fig. VI. 1), we see its very discontinuous behavior. As the temperature is increased, both of the NaCl solutions and the water decrease in density in a fairly regular fashion but the sweat samples show marked discontinuities culminating in a high point for both samples in the region 24-29°C. The plot of relative viscosity versus temperature also shows this sudden irregularity in the region 24-29°C. It is of interest that Snyder and Todd (11) in a study of blood components such as serum and plasma reported complete linearity in the relative viscosity over the range 0-45°C (14).

One cany only speculate on the cause of this anomalous behavior of human sweat. Wells (12) has attributed such behavior in biological fluids to their proteins and collodial suspensions of cells. Wells and his co-workers emphasized the point that systems with suspended particles are non-Newtonian and therefore have anomalous flow characteristics. Other workers (4, 6) have also reported anomalous flow properties for blood systems, noting that the rate of shear and applied stress are not proportional over a wide range as the Newtonian hypothesis states. The possibility also exists that the behavior of the sweat is influenced by the nitrogenous compounds known to be present in human eccrine sweat (15). If present, some compounds such as mucopolysaccharides might polymerize at a given temperature. Thus the abrupt increase in relative viscosity might be explained.

Our data suggest that the viscosity and density of sweat cannot be accounted for as if it were water or a simple saline solution. Thus in calculating the wetting of skin and latent heat of vaporization, one should be aware that past calculations may be based on erroneous assumptions.

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Table VI. 1. Density, Absolute Viscosity, and Relative Viscosity of 11 Samples of Human Eccrine Sweat. Spring 1966. (NASA Grant 14-005-050)

Sample Identification	Density gm/ml	Absolute Viscosity Centipoises	Relative Viscosity**
JB 27 Jan	0.99933	0.9290	1.0231
JB 10 Feb	0.99945	0.9092	1.0013
JB 21 Feb	1.00018	0.9118	1.0042
JB 7 Mar	1.00006	0.9176	1.0106
EB 27 Jan	1.00230	0.9170	1.0099
EB 18 Mar*	1.00056	0.9108	1.0031
PM 28 Feb	1.00342	0.9228	1.0163
JN 14 Feb	1.00480	0.9334	1.0280
JN 7 Mar	1.00488	0.9280	1.0220
JM 15 Feb	1.00287	0.9239	1.0102
VC 18 Mar*	1.00157	0.9138	1.0064
Average	1.00176	0.9197	1.0128

*5 samples pooled for the period 14-18 March.

**Relative to water at the same temperature.

Table VI. 2. Temperature Dependence of Density and Viscosity of Water, Solutions of Sodium Chloride, and Human Eccrine Sweat. Spring 1966. (NASA Grant 14-005-050)

Temperature °C	Density gm/ml	Discharge Time sec	Absolute Viscosity Centipoises
A. Distilled Water			
14.3	0.99920	431.4	1.1617
19.3	0.99835	380.0	1.0224
24.3	0.99722	337.6	0.9080
29.3	0.99585	302.6	0.8158
32.4	0.99492*	283.8	0.7617*
B. Solution of NaCl, 0.04 M			
14.3	1.00092	432.8	1.1675
19.3	1.00012	380.0	1.0242
24.3	0.99917	338.8	0.9130
29.3	0.99726	302.5	0.8167
32.4	0.99692	284.4	0.7648
C. Solution of NaCl, 0.25 M			
14.3	1.00969	434.4	1.1820
19.3	1.00920	384.5	1.0458
24.3	1.00800	342.0	0.9298
29.3	1.00646	306.6	0.8331
32.4	1.00592	291.1	0.7899

Table VI. 2. (Continued)

D. Eccrine Sweat of Subject EB.			
14.3	1.00292	433.1	1.1706
19.3	1.00352	380.4	1.0288
24.3	1.00056	337.5	0.9108
29.3	1.00275	305.1	0.8282
32.4	0.99907	284.3	0.7662
E. Eccrine Sweat of Subject VC.			
14.3	1.00315	432.3	1.1687
19.3	1.00090	381.5	1.0290
24.3	1.00157	338.3	0.9138
29.3	1.00258	305.0	0.8278
32.4	1.00203	286.2	0.7736

*Data of Hodgeman, 1951.

FIG. VI, 1

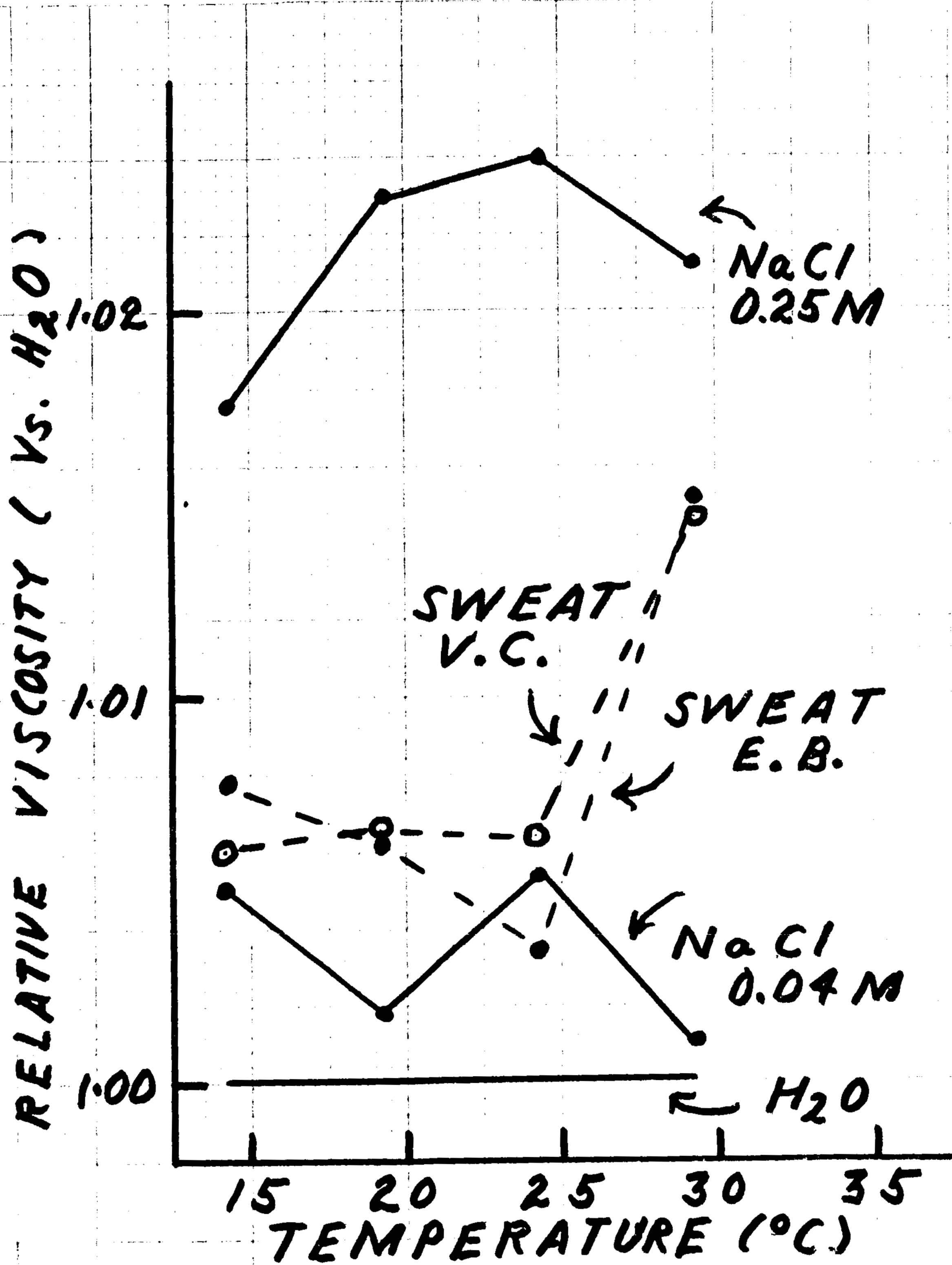

Figure VI. 1--The relationship between the relative viscosity of water, solutions of sodium chloride (0.04 M and 0.25 M), and two specimens of human eccrine sweat at temperatures from 14°C to 30°C.

SECTION VII. SECRETORY PRESSURE OF THE SWEAT GLAND

Introduction

Kittsteiner (1913) reported that even when a pressure of 250 mm Hg was applied to the forearm skin surface using a glass funnel, sweat secretion still continued. He concluded that the secretory pressure must be higher than 250 mm Hg. Shelley and Hurley (1953) used a similar method for apocrine sweat glands and concluded that the secretory pressure from axillary apocrine sweat glands is higher than 225 mm Hg.

Takahara (1936) studied the discharge of sweat from a single sweat gland of the palm by means of cannulation and found that sweat is secreted periodically at an interval of about 2 minutes at rest and 20 to 40 seconds during active sweating. Arguing from this periodicity, he attributed the energy of sweat secretion to the myoepithelia of the sweat gland.

Looking at other secretory organs, Wiedeman and Stone (1962) showed that the secretory pressure of the human mammary gland is about 10 mm Hg and Yoshimura *et al*. (1962) showed that of human parotid glands to be 12 to 13 mm Hg. This large difference between sweat glands, which are single glands, and multilobular glands like the mammary gland and salivary gland led us to attempt to measure the secretory pressure of single eccrine sweat glands.

Methods

Palmar sweat glands of a healthy female from India who has hyperhidrosis of the palm were studied. Mental calculation was used as the stimulus for sweating.

A schematic diagram of the apparatus is shown in Fig. VII. 1. The sweat pores on the palmar surface of a finger are about 50μ in diameter and lie about 500μ apart. One such pore is covered with a capillary the inner diameter of whose tip is about 100μ. A stereoscopic microscope and micro-manipulator are used for positioning. The capillary is applied from the same axis as that of duct of the sweat gland. This can be observed by applying a weak light from a slanted position to the skin. The tip of the capillary is sealed to the skin by collodion. The reason why cannulation was rejected was that to cannulate into the sweat gland the tip of the capillary should be about 35μ; such a capillary would reduce the pressure greatly. The other end of the capillary is connected

to the transducer part with polyethylene tubing fitted to a three-way stopcock. The transducer part consists of a glass capillary (i.d.: 0.5 mm; o.d.: 0.8 mm) connected through polyethylene tubing with two glass tubes from a venous pressure outfit; this tubing has a bigger inner diameter than the glass capillary. The glass capillary part contains a small amount of mercury and is held within a sensing unit. The sensing unit (Fig. VII. 2.) consists of a light source, two lenses, a slit, and a photocell. The light beam from a lamp is converged to the meniscus of mercury in the glass capillary through a slit, and another lens placed on the other side of the capillary converges the divergent light from the capillary to the head of a photocell. All capillaries and polyethylene tubing are filled with water. The secretory pressure of a sweat gland is conducted to the meniscus of the mercury and changes the level of mercury. This change can be sensed as a change of light intensity by the photocell. The signal from the photocell is amplified by a DC amplifier and recorded by a Sanborn recorder. The sensitivity of the unit can be modified by (a) changing the sensitivity of the DC amplifier or (b) changing the amount of mercury filling the capillary.

For calibration, changes of water level within the glass tube are caused and the pressure recorded.

Results

So far, two trials have been performed. The recording of one of the experiments is shown in Fig. VII. 3.; the secretory pressure varied between 1.2 cm H_2O and 7.6 cm H_2O. The periodicity of the secretion is between 24 seconds and 152 seconds. These values agree with the data of Takahara (1936) on periodicity, but not those of Kittsteiner (1913) or Shelley and Hurley (1953) on secretory pressure.

Discussion

The secretory pressure of sweat glands in our experiments is less than 1/300 of Kittsteiner's results. As mentioned before, his results place the sweat gland in quite a different position from the mammary glands or salivary glands taking into account their histological structures. His technique and ours are quite different. He applied indirect pressure over a wide area. We measured the pressure at the duct. It is possible that his pressure would be widely diffused and would not stop sweating even if the actual gland pressure were much lower.

One problem of this method is that the original recording has a drift of the base line. This ranges between 6 mV/min. and 12 mV/min., so that a correction 9mV/min. for drift has to be made. Another is that this transducer has a very small zone of linearity. Therefore the mercury level must be readjusted during experiments. After each readjustment, it takes some seconds until the recording becomes stable. The fact that this transducer has hysteresis during calibration is another drawback.

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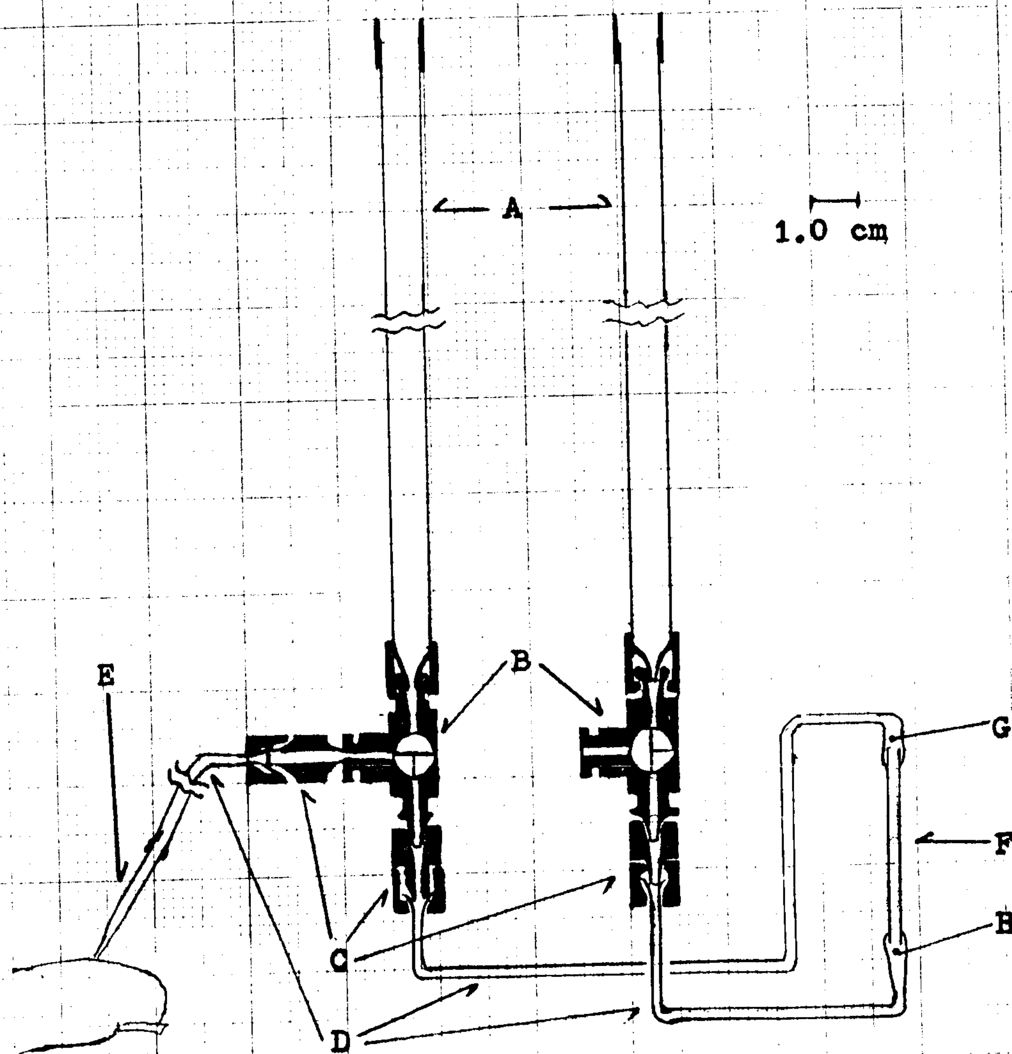
FIG. VII. 1



A: Glass tube for venous blood pressure measurements.
B: Three way stop cock.
C: Connector.
D: Polyethylene tubings.
E: Glass capillary pipet.
F: Glass capillary.
G: Water.
H: Hg.

Figure VII. 1--Apparatus for measuring the secretory pressure of a single sweat gland in the finger tip of a human.

12-282
20 Squares to the Inch

SECTION VIII. SUMMARY OF PROGRESS FOR THE PERIOD 1 JANUARY 1966--30 JUNE 1966 (NASA GRANT NGR-14-005-050)

A. Chemical Composition of Sweat Compared with its Osmotic Pressure

The following constituents of sweat were measured: sodium, potassium, calcium, magnesium, ammonia, chloride, lactate, urea, total nitrogen. Regularly the sum of the anions was about equal to that of the cations. However, the sum of all constituents did not always fully account for the osmotic pressure (freezing point). An "osmotic deficit" of up to 12 percent was identified in some specimens. Those with the greatest absolute deficit were the most concentrated, and generally also had a large undetermined nitrogen residue, that is the difference between total nitrogen and the sum of urea and ammonia. These results confirm and extend previous observations by Adams, Johnson, and Sargent (1958) and leave unresolved the opposite findings of Foster (1961).

B. Acid-Base Properties of Sweat

Under the conditions of these experiments arm sweat was collected in a vapor impermeable bag, but not anaerobically. *In vitro*, neither the lactic acid-lactate system nor the carbonic acid-bicarbonate system could be shown to be related to changes in acidity. However, changes in ammonia were closely correlated with changes in acidity. Titration curves showed at least four discontinuities. Fourteen amino acids were detected. Only three occurred in amounts over 0.4 mMole per liter: serine, alanine, and glycine.

C. Viscosity and Density of Sweat

The viscosity and density of sweat were compared with those of distilled water and solutions of sodium chloride. The viscosity of sweat is not the same as that of saline solutions of the same density, but is higher. It is variable from subject to subject. A very interesting anomaly was observed at temperatures between 29°C and 35°C: the relative viscosity of sweat increased with temperature in this range, as contrasted with that of saline solutions, which decreased.

D. Secretory Pressure of the Individual Sweat Gland

A system has been developed for measuring the secretory pressure of a single sweat gland. A glass capillary of approximately twice the diameter of the pore is applied to the sweat gland pore. Pressure changes are transmitted to a mercury-water column, and an optical scanning device detects changes in the height of the column. In two trials, the secretory pressure was around 10 cm of water, and the gland changed pressure rhythmically in a cycle of about 2 seconds.

E. Preparation of the Skin and Collection of Sweat, and Processing of Sweat Prior to Analysis

A routine for preparing the skin for collecting sweat has been developed. The steps are: shaving the skin 24 hours ahead of the experiment; washing the skin with neutral, non-allergenic detergent; rinsing with distilled water; and starting actual collection ten minutes after the onset of sweating. Clear, non-turbid sweat can be obtained by freezing, thawing, and then centrifuging.