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The Effect of Adaptation on the Temperature Difference Limen

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HISTORICAL SKETCH

Although the adaptation phenomenon has been recognized as an important factor in dealing with the temperature sense, very little systematic experimental work has been done in that direction. What has been done has been mainly in connection with work on the difference limen for temperature. The present survey does not attempt to cover the literature on the difference limen but only that which involves adaptation directly or indirectly, since the experiment reported was undertaken with a view to getting some light on the adaptation process itself and the difference limen was used as the most convenient indicator available.

Fechner,[1] working in 1855 on the application of the Weber law to temperature sensitivity, used two clay vessels of water in which the first and middle fingers of the right hand were immersed. He says, "The two fingers used for the experiment were first immersed in one of the two vessels until they reached a constant temperature, then immersed alternately in each vessel until a judgment had been made." Just what Fechner meant by a "constant temperature" it is difficult to guess. It may have been a state of complete adaptation or a state of relatively constant temperature sensation. He makes no allowance for this in computing his results but uses as his physiological zero the mean between freezing and blood temperature. Computing on this basis and using the method of minimal changes he finds the difference limen between 10° R. and 20° R. too small to give satisfactory conclusions but finds the Weber law may be applied betwen 20° R. and blood temperature.

Nothnagel[2] later investigated sensitivity to temperature differences by means of metal cylinders applied to the forearm and also by immersing one finger after the method of Fechner. At

[1] Fechner, G., Th. Elemente der Psychophysik, vol. I, 1889. pp. 201-211.

[2] Nothnagel, H., Beiträge zur Physiologie und Pathologie des Temperatursinns. Deutsch. Archiv. f. Klin. Med. ii, 1867, pp. 284-299.

ordinary room temperature of 18° C. he finds that the temperature of the skin on the hand will lie usually between 33° C. and 36° C. Under these conditions the finest temperature difference perception is found with temperatures between 27° C. and 33° C. The difference limen increases slowly between 37° C. and 39° C. and very rapidly between 39° C. and 49° C. It also increases slowly between 27° C. and 14° C. and rapidly between 14° C. and 7° C. An ice bag was laid on the skin of one forearm for a period of from ½ to 1 hour and at the end of this time warm and cold were felt much less intensely on this area than on the other arm. Where there had been a difference limen of from .3° to .2° C. normally there was now a difference limen of from 1° to 3° C. The pain threshold for warm temperature was also raised from 49° C. to 54°-56° C. One hand was immersed for a period of from ½ to 1 hour in water of from 42° C. to 45° C. and the difference limen on this hand compared with that of the normal hand. The smallest difference limen for the normal hand lay between .2° and .1° while for the immersed hand it lay between .4° and .3° C. The pain threshold in this case was lowered from 47° C. to 46.5° C.

Thunberg[3] states that a finger may be adapted to 11° C. so that 12° C. will give a warm sensation and similarly a finger may be adapted to 39° C. so that a slight lowering of the temperature will produce a cold sensation.

Goldscheider,[4] in working with adaptation to temperature, was mainly interested in the effect of adaptation to extreme temperatures. He states that adaptation to extreme cold or warmth (15°-40° C.) blunts the temperature sensibility for both cold and warm. If one warms a cold spot the temperature cylinder will elicit a weak cold response for some time thereafter and one will regularly get a weaker cold response with the same stimulus if applied to a warmed area than if applied to a normal area. This holds also for warm points. He puts a finger in water of 15° C. and the corresponding finger of the opposite

[3] Thunberg, T., Upsala Läkaref. förh. 30, 1894-95, p. 521.

[4] Goldscheider, A., Physiologie der Hautsinnesnerven, vol. I, 1898. pp. 1-432

hand in water of 32° C. After 10 seconds both were plunged in water of 40° C. and the lukewarm finger felt the warmth more keenly than the cold finger. This is due, he thinks, to the fact that the extreme cold has blunted the sensitivity of the finger to warm as well as to cold stimuli. He thinks it probable that cooling lowers more the sensibility of the cold nerves than of the warm nerves and that warming lowers more the sensibility of the warm nerves than of the cold nerves. He adapted a finger to 40° C. and on plunging it into water of 30° C. he experienced a sensation of coolness but this was not as strong as the sensation of coolness which he experienced when he plunged a finger adapted to 30° C. into water of 20° C. In the same manner water of 30° C. will feel less cool to a finger adapted to 35° C. than 25° C. will feel to a finger adapted to 30° C. If a finger is adapted to 35° C. and then plunged into 30° C. it will feel less cool than a finger adapted to 36° C. and plunged into 30° C. This relation will hold for adapations to 37° C., 38° C., and 39° C. but with adaptation to 40° C. the sensation of coolness received from 30° C. decreases in intensity and with adaptation beyond 40° C. there will be no cool sensation received from 30° C. The similar boundary for cold adaptation is 21° C. Adaptation to extreme cold temperatures will also lower the sensitivity of the cold points to electric or mechanical stimuli. The effect of adaptation does not pass away immediately. Goldscheider found that if he adapted a cold spot to the anaesthesia point it would not react normally for an appreciable interval and that this interval was not lessened by exposing the area tested to a warmer medium during the period of recovery from adaptation.

Holm[5] experimented on the time duration of temperature sensations before complete adaptation. He applied a metal flask, with a thin bottom about 5 sq. cm. in area, to the skin and kept it there until complete adaptation was reached. The flask was filled with water kept at a constant temperature during the experiment and the following temperatures were used: 30° C., 25° C., 20° C., 15° C., 10° C., and 5° C., characterized as cold

[5] Holm, K. J., Die Dauer der Temperaturempfindungen bei constanter Reiztemperatur. Skand. Archiv. f. Physiol., vol. 14, 1903, pp. 242-248.

stimuli; 40° C. and 45° C., given as warm stimuli. Five tests were made with each temperature with the following results.

Average length of adaptation time for	45° C.	was	152″	Mean variation	8.2
	40° C.		126″		20.8
	30° C.		31″		3.2
	25° C.		47″		3.6
	20° C.		72″		2.4
	15° C.		112″		12.4
	10° C.		165″		6.
	5° C.		210″		24.

It is to be noted that there is a marked increase in the mean variation as the temperatures rise over 30° C. and fall below 20° C. There is a correspondingly sudden increase in the length of the adaptation time for these temperatures. It is stated that during the time of adaptation the sensation fluctuates in that it disappears and reappears several times before it finally disappears permanently. Holm draws no conclusions from his results.

Alrutz,[6] in experimenting with conditions for perception of heat, found that under normal conditions a temperature of 41° C. applied to the arm gave a strong and unpleasant hot sensation. He adapted the arm for from three to five minutes to a temperature of 20.5° C. and when he again applied a temperature of 41° C. to the arm, a weaker, less unpleasant hot sensation was felt. Applied to an arm whose skin temperature was 32° C. a temperature of 14.5° C. gave a cold, unpleasant sensation. Applied to an arm which had been adapted three to five minutes to 41° C. a temperature of 14° C. gave a slower, weaker and not unpleasant cold sensation. In testing the threshold limen for hot he found that the limen differed with the initial temperature of the skin area to which the test was applied. As this temperature increased the hot limen rose and by artificially warming the skin the hot limen could be raised to 40° C. Similarly by adapting the skin to 22° C. the hot limen could be lowered to 32° C. The limen for paradoxical cold was also lowered by cooling the skin.

[6] Alrutz, S., Untersuchungen über die Temperatursinne, Zeit. f. Psych., vol. 47, pp. 241-286, 1908.

M. von Frey[7] calls attention to the fact that if an adapted area be subjected to a change in the intensifying direction a sensation will ensue. An "adapted temperature spot" will moreover respond to electrical and mechanical stimuli.

In 1910 Voigt[8] attempted, by experimental methods, to demonstrate the degree of objective adaptation which corresponds to adaptation which is subjectively complete. He argued that if adaptation were actually perfect he should be able to adapt one hand to 30° C. and the other to 35° C. until the two temperatures felt alike. He should then be able to plunge the 30° C. adapted hand into 35° C. and the 35° C. adapted hand into 40° C. and have them still feel alike. The fact that the two latter temperatures will not feel alike under such circumstances is evidence that adaptation is not objectively perfect.

He used in his experiment three enameled sheet iron vessels with double walls sixteen inches thick and with a capacity of three and three-fourths litres. The vessels were filled with water kept at a constant temperature by electric coils in the double walls or by ice in the water. The vessels 1, 2, and 3, stood next each other with 1 at the left of the observer. The left hand was submerged to the knuckles in 1 and the right hand in 2 for a period vary-from nine to fifteen minutes. At the end of this period the left hand was plunged into 2 and the right hand into 3 and an immediate judgment given as to whether 3 were higher, equal to, or lower than 2. Between 1 and 2 there was always a difference of five or ten degrees. The difference between 2 and 3 was varied, always in the direction in which 2 varied from 1, until a judgment of "no difference" was obtained. The amount of this difference was then compared with that between 1 and 2 and the ratio given as the degree of absolute adaptation attained.

Voigt, himself, was the only observer in the experiment and the temperatures were controlled by an assistant. The experiment covered about forty series of experiments, each series

[7] Frey, M. von, Physiologie der Sinnesorgane der menschlichen Haut. Ergeb, d. Physiol., vol. 9, 1910, pp. 351-369.

[8] Voigt, A., Über die Beurteilung von Temperaturen unter dem Einfluss der Adaptation. Zeit. f. Psych., vol. 56, 1910, pp. 344-355.

comprised of ten experiments. The following results were obtained.

Series No.	Initial adaptation temperatures 1 2	Final difference between 2 and 3	Ratio of difference between 2 and 3 to difference between 1 and 2
1	10°-15° C.	.5° C.	0.1
2	15°-20° C.	.5° C.	0.1
3	35°-40° C.	1.0° C.	0.2
4	40°-45° C.	1.0° C.	0.2
5	10°-20° C.	1.0° C.	0.1
6	30°-20° C.	1.5° C.	0.15
7	35°-25° C.	2.5° C.	0.25
8	35°-45° C.	1.5° C.	0.15
9	45°-35° C.	2.0° C.	0.2

Voigt also observes that adaptation to the point, where perception of difference between the adaptation temperatures vanished, never occurred even if a whole hour were given to adaptation. The maximum degree of adaptation usually took place within two minutes. He regards the degree of adaptation possible for the hands, as astonishingly slight and finds no proportional relation between different adaptation degrees and different points on the thermometric scale although he expresses the hope that with more elaborate apparatus and more extended investigation such a relationship might be found to obtain.

In taking the ratio of the actual difference between 2 and 3 to the difference between 1 and 2 as a measure of the degree of adaptation possibility Voigt is presupposing that the hand in 1 is as near perfect adaptation to temperature 1 as the hand in 2 is near perfect adaptation to temperature 2.

His results indicate that, with one hand adapted to 10° C. and the other to 15° C., .5° C. is near the difference limen for 15° C. If both hands were equally nearly adapted to their respective adaptation temperatures then such a method would give an indication of the relative potency of adaptation to different temperatures as judged by its effect on the difference limen. But there is no reason to suppose that adaptation is as nearly perfect for 10° C. as for 15°C. Beyond the fact that Voigt's method demonstrates there is not perfect adaptation there can be no absolute determination of the degree of adaptation by means of the difference limen because any difference limen determined for temperature sensations must be determined under some condition of adaptation. This precludes any possibility of what might be termed a normal difference limen for purposes of comparison. Moreover, in series 1, 2, 3, 4, 5, and 8 Voigt is determining a difference limen in the direction of increasing thermometric temperature whereas in series 6, 7, and 9 the difference limen determined is in the direction of decreasing thermometric temperature. This fact makes these latter series incomparable with the others.

This completes the available experimental data on temperature adaptation. The present experiment undertook to investigate the comparative effect of adaptation to different temperatures on the difference limen for given temperatures, chosen more or less arbitrarily but extending from 40° C. to 17.5° C. at intervals of 2.5° C. Apparatus was devised for keeping water, the adaptation medium used, at any given temperature for an indefinite period.

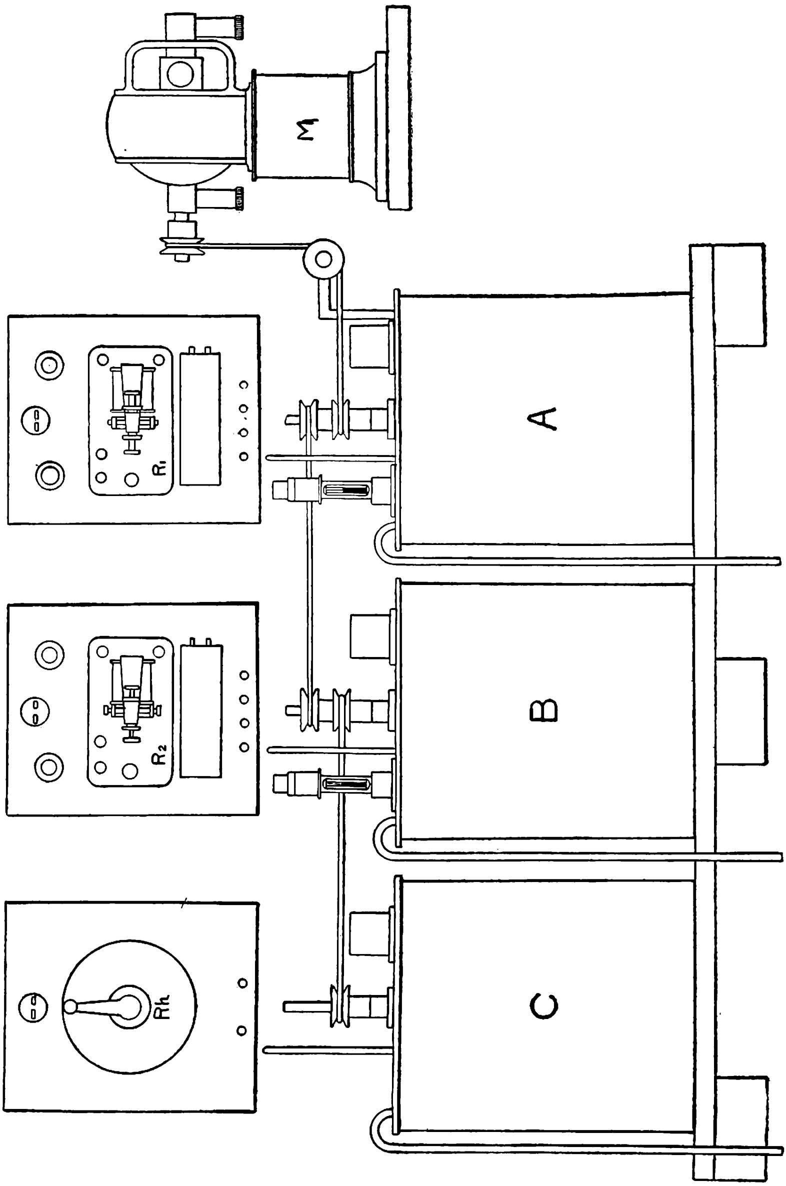


Fig. I.

A. B. C.—Stone Jars.
M—Motor.
R_1—Relay for Jar A.
R_2—Relay for Jar B.
Rh.—Rheostat for Jar C.

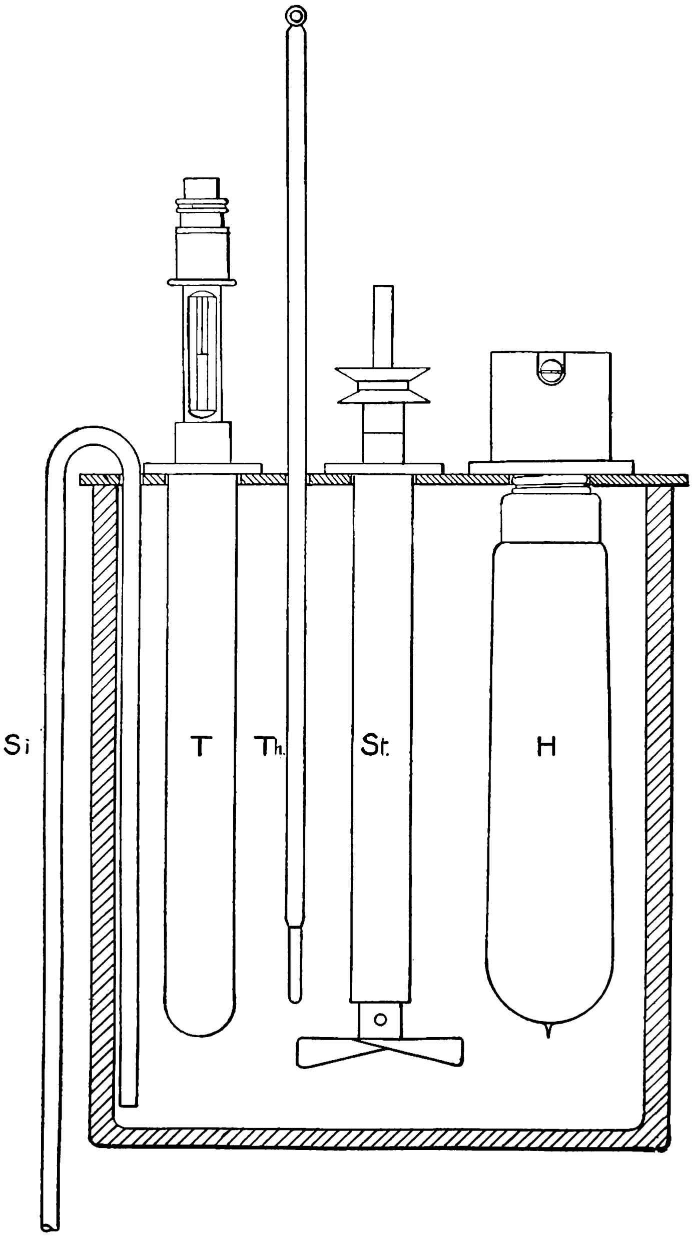


Fig. II.

H—Luminous Heater.
St.—Stirrer.
Si.—Siphon.
T—Thermostat.
Th.—Thermometer.

APPARATUS AND METHOD

The apparatus consisted of three round stone jars, A, B, and C, each holding four gallons of water. An asbestos cover was fitted to each jar and had, near one edge, an aperture, eight by one and a half inches long through which the hands were dipped into the water. Beside this aperture was a small hole through which a Centigrade thermometer, registering to tenths of a degree, was hung so that it registered the temperature of the water where the hands were dipped. From the centre of the cover depended a rod carrying a brass stirrer which was kept revolving by a system of pulleys connected with an electric motor. This gave the water motion enough to keep the temperature even but did not set up current enough to interfere with adaptation. The water was heated by means of a 500-watt luminous heater attached to the cover opposite the aperture for the hands. Near the heater was attached the thermostat. The thermostat consisted of a long glass tube extending down into the water the entire length of the jar and filled with mercury. The glass tube was attached to a steel cap having a hole through the center three-eighths inches in diameter. Inserted in this central hole and adjustable was a steel tube. Through the center of this steel tube was a small glass tube. The mercury on expanding was forced up into the glass tube and came in contact with a fine platinum wire which was adjustable. The mercury on making contact with the platinum wire completed an electric circuit which in turn by means of a relay closed the heating circuit. When the mercury dropped, breaking contact with the platinum wire, the heating circuit was again opened. The accompanying sketches [see Figures III and IV] show the details of this arrangement. The thermostat regulated to .1° C. for an indefinite period and was adjustable to any temperature.

The temperatures of A and B were controlled by thermostats. C was similar to A and B except that it had no thermostat and the heater was connected directly with a rheostat controlled by

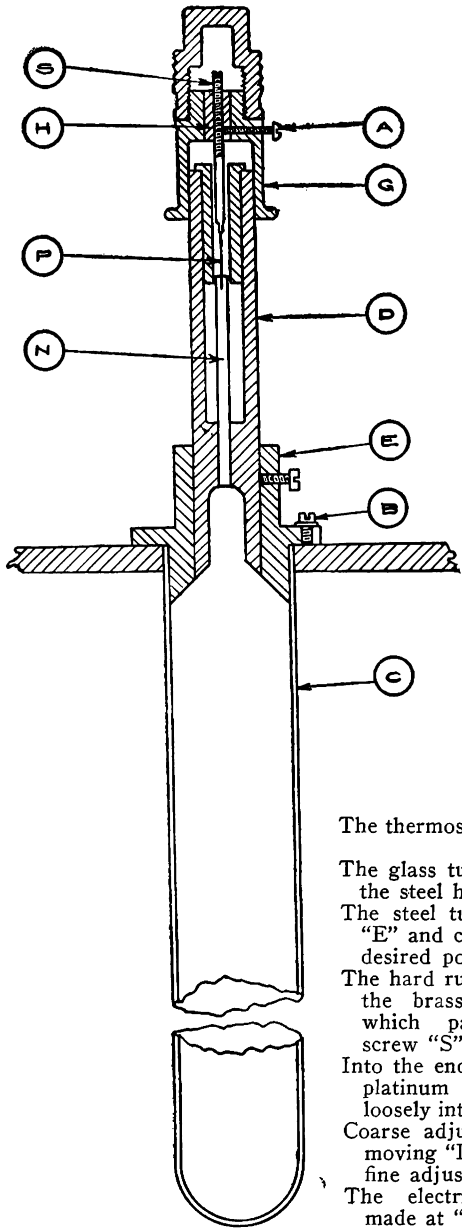


Fig. III.
The thermostat used in the experiment.
The glass tube "C" is attached to the steel head "E".
The steel tube "D" is fitted into "E" and can be adjusted to any desired position.
The hard rubber head "G" carries the brass plug "H" through which passes the adjusting screw "S".
Into the end of "S" is fastened a platinum needle "P" which fits loosely into glass tube "N".
Coarse adjustments are made by moving "D" up or down and the fine adjustments by screw "S".
The electrical connections are made at "A" and "B".

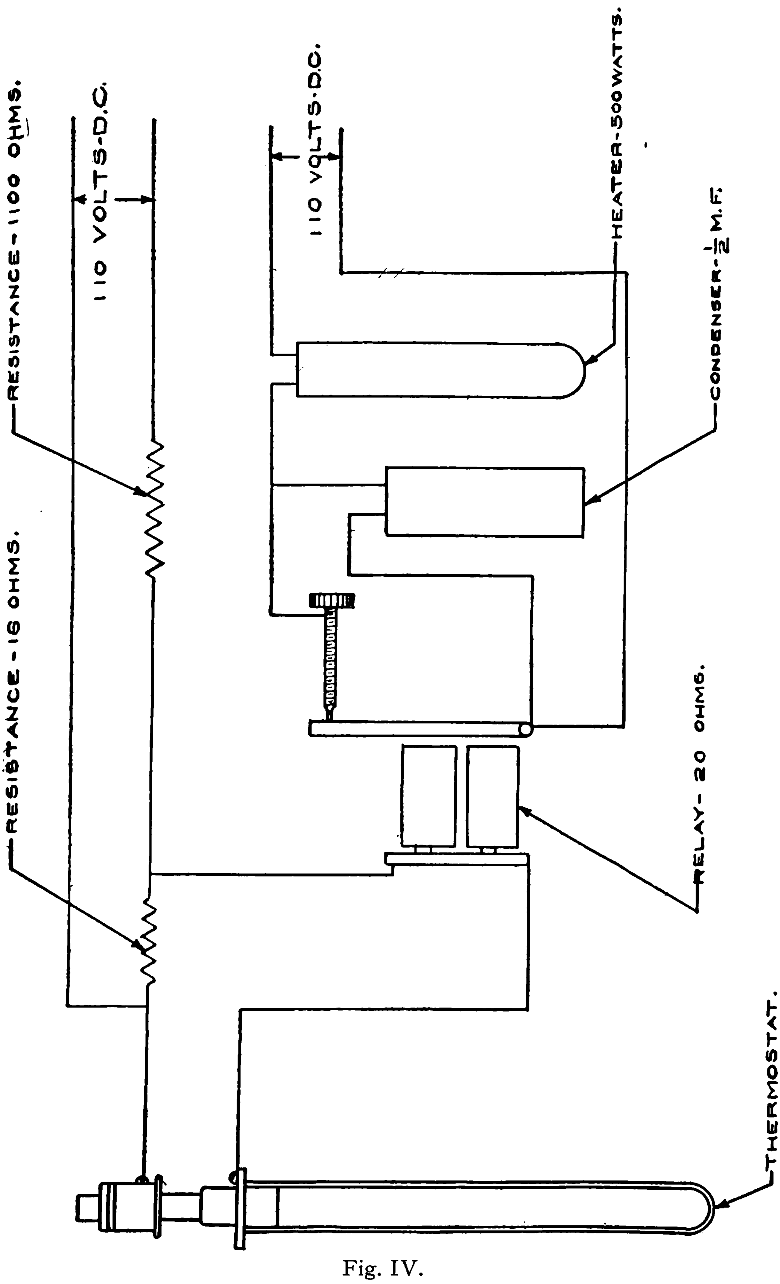


Fig. IV.
The electrical connections for the heater and thermostat.

hand. This was considered necessary at first because C was to be used mainly as the variable and it was not thought possible to vary temperatures and reproduce them with the requisite frequency by means of the thermostat. When we came to use the thermostats, we found that they were fully as satisfactory as the rheostat for this purpose. Jar A was always used as the adaptation jar and B and C were used in turn as the standard and variable in the determination of the limen. The subject was always in ignorance as to which jar was being used as the variable. The fact that the heating lamps were constantly shifting on and off made it possible to change the relative position of the standard and variable several times in the course of one experiment without the subject suspecting the change.

Water could be drawn off from the jars by means of siphons and when it was necessary to cool the temperature it was done by means of ice water poured in at the top. For the temperatures below room temperature ice was kept in the water and the thermostat set as usual. As the water kept cooling below the necessary temperature the thermostat kept it regulated.

The temperatures used throughout the experiment were 40° C., 37.5° C., 35° C., 32.5° C., 30° C., 27.5° C., 25° C., 22.5° C., 20° C., and 17.5° C. These limits were used to avoid the paradoxical cold in the upper temperatures and the painfully cold in the lower.

The method in general was the same for all the experiments. The observer stood before the adaptation jar A and rested his hands on the cover of the jar with the fingers dropped through the aperture so that the water reached to the second knuckles. The hands were held quietly until adaptation was complete when the subject raised his hands and dipped them, one into jar B and one into jar C. The subjects were cautioned agäinst dipping their hands in above the second knuckles or dipping one hand in farther than the other or before the other. After a little practise they were able to follow directions. Every other judgment was taken with the hands crossed, the left hand in B and the right hand in C and every other judgment with the hands straight, the left hand in C, and the right hand in B. This was done in order to avoid an association with the right or left hand. The hands were dipped in and taken out again immediately and the subject asked to give his immediate judgment. After the judgment was given the hands were returned to jar A to be re-adapted in preparation for the next test. The method of right and wrong cases was used in determining the limen.

Experiments were carried on with each subject three times a week for an hour at a time. At the beginning of each hour preliminary tests were made by dipping the two hands after adaptation into jar B to make sure that water of the same temperature felt alike to both. After three successive judgments of "alike" under such circumstances the experiments were begun. Only one adaptation temperature was used in the course of an hour. Four observers were used, all of them graduate students in the Department of Psychology of the University of Chicago and trained in psychological observation.

The length of time of adaptation varied considerably for different individuals and for the same individual at different times. Therefore there was no effort made to keep the time of adaptation constant. Adaptation was said to be complete when the observer was no longer conscious of sensations of temperature from the area submerged in water. Because the length of adaptation time depends on so many factors such as initial temperature, blood pressure and other possible physiological factors there was no attempt made to correlate it with the results. In general it may be noted that the first adaptation period during an hour's experimenting was noticeably longer than the subsequent periods.

In his experiments on adaptation Voigt notes that adaptation was never complete enough to make him oblivious of the difference between the two adaptation temperatures he was using. In some of our preliminary work, reported on at the annual meeting of the American Psychological Association in 1911, in which experiments were made involving simultaneous adaptation of the two hands to temperatures differing by 5° C. and ranging from 40° C. to 17° C., five different subjects, two of them trained observers, reported complete adaptation in six hundred experiments. The four observers, used in the present experiment all agreed that a state of adaptation could be reached so complete that there was no sensation of temperature present. Although adaptation might seem more complete if both hands were in the same temperature than if they were in different temperatures, we have assumed on the basis of the previous experiments that adaptation may become subjectively complete and have used the introspection of the observer as a criterion of adaptation. Voigt was his own subject and states that he always knew the adaptation temperatures at the time of the experiment. It is possible that this fact accounts for his failure to obtain complete adaptation.

RESULTS

Introspective evidence on the process of adaptation

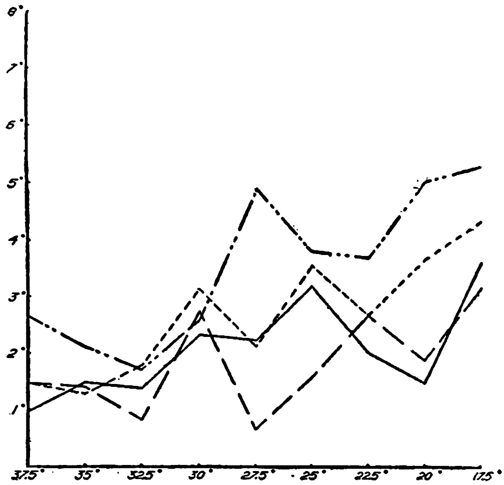
As has been said, the length of time of adaptation varied for individuals. Some subjects obtained complete adaptation within two minutes and others might have to spend twenty minutes in obtaining complete adaptation at the beginning of an hour's experimenting. In general the adaptation to extreme temperatures took longer than to moderate temperatures. The process of adaptation was marked, however, by certain characteristics which obtained for all subjects.

Adaptation did not take place gradually with a slow fading of the temperature sensation. There was scarcely any noticeable change in the sensation for a longer or shorter time, depending on the individual, and then the temperature sensation faded with remarkable quickness. It usually faded so quickly that the subject could give no adequate report of the process of its going. It merely was and then was not. But this first disappearance was not permanent. The sensation returned and there was likely to be a fluctuation in and out of consciousness for some little time before adaptation was complete and permanent. Each time the sensation returned it was a little fainter and lasted a shorter time. Holm[1] notes the same fluctuation in his account of the duration of temperature sensations before complete adaptation. The tips of the fingers were most sensitive and with 40° C. or 17.5° C. there was usually a tingling sensation in the tips of the fingers. This tingling fluctuated also but the fluctuations did not parallel those of the temperature sensation. Several of the subjects spoke of a feeling of heaviness in the fingers which increased as the hands remained in the water until just before adaptation set in, when the fingers felt noticeably lighter and more comfortable. With the disappearance of the temperature sensations the feeling of wetness disappeared and

[1] Holm, K. J., Die Dauer der Temperaturempfindungen bei constanter Reiztemperatur. Skand. Archiv. f. Physiol., vol. 14, 1903, pp. 242-248.

the fingers felt as though hanging in the air. The subject who experimented most with adaptation to extreme cold (17.5° C.) frequently noted the fact that the cold might sometimes be "referred to the water, that is it is the water that feels cold," and at other times the cold is "localized in the fingers. They feel as though they were the things that were cold." There was also with this temperature a dull ache as well as a sharp tingle and the two did not occur simultaneously but alternately.

The following report of an adaptation experience, taken at the beginning of a series with adaptation to 40° C., is typical of the adaptation process. "Pretty warm. Slightly tingling sensation. Another tingling starts at the bottom of fingers and goes up to wrist. Fingers feel heavy and soggy,—different from just wet. Tingling along outside of skin like an electric shock. Heavy fingers. Warm at upper end of fingers. Warmest just at edge of water. Tingling keeps on. Still pretty warm. Just about same temperature. Might be getting warmer. Creepy feeling goes up on skin especially on outside of little fingers. Still feels warm but perhaps not quite so warm. Warm at edge of water, not quite so warm. Tingling in left hand. Doesn't feel so warm any more—still warm just at edge of water. No temperature at tips of fingers. Little skin sensations of tickling, as though the skin contracted here and there—getting a little warmer. On the outside of hand near edge of water it is warm. Tingling sensation clear down at tips of fingers. About the same temperature, not quite so warm. More tingling especially on little finger. Heaviness has disappeared—feel lighter—pretty warm—not particularly warmer—slightly warmer near the edge of the water—now all feels cooler—warmth seems to settle on one finger and then on another—goes from place to place. No warmer—cooler if anything—not so much tingling—what there is is weak—does not go so far. Not quite so warm—tingle now and then—about the same, warm near the edge of water—no heaviness about fingers, general contracted feeling about the skin—pretty wet—warm current seems to come up against them but not so warm as has been—warm parts in middle and top—warmth when it comes is usually on back of fingers—not so warm as it has been—once in a while a warm current comes along—very little warmth at all except at edge of water. When warmth comes now it does not seem so much at skin as on inside of finger. When fingers move it feels as though they were against sandpaper. Little warmer now. Still feels rather warm especially at edge of water. Not nearly as warm as at first. Rather warm, especially on back of little fingers. Heat is concentrated at back of fingers at edge of water —front part of fingers feels almost cool—slight tingle—fingers feel dried up—no warm currents—feel lighter, cooler—little fingers just a little warmer—still feels warm but not nearly so much as before—almost cool sometimes—still tingling cool in parts—twitches don't run up but localize in a joint—still warmth at edge of water—getting more moderate again—don't feel warmth much at all—just hazy feeling of warmth around edge of water. Warmth practically all gone except now and then on edge of little finger. Fingers feel as though it were warmth of blood rather than water. No more localized in fingers than in hand or in wrist—feels almost normal—adapted."

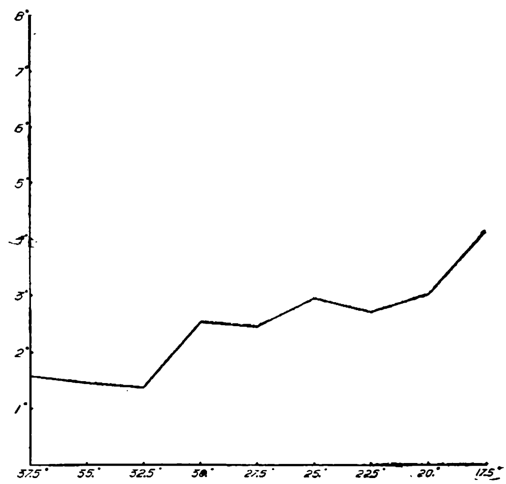


Graph I. Curve showing difference limen for different temperatures after adaptation to 40° C. The temperatures for which the difference limen was determined are represented on the abscissa and the amount of the difference limen on the ordinate.

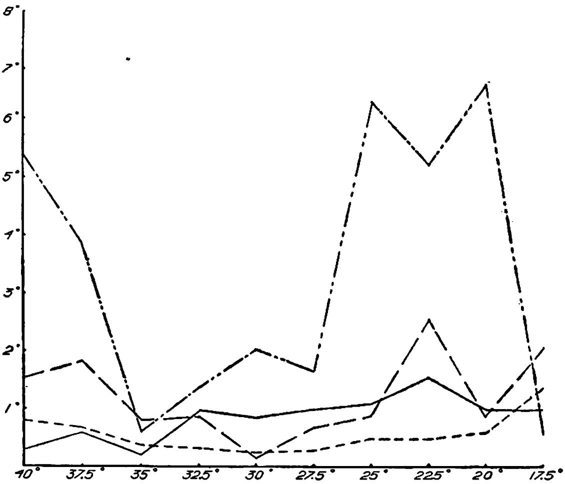
——— ——— ——— ——— Subject A
———————————————— Subject B
—— — — —— — — —— Subject C
— — — — — — — — — — — — — Subject D

TABLE FOR GRAPH I

Temperature for which difference limen was determined.	Number of tests involved in determining difference limen.				Interval at which the percentage of right cases varied from the standard.			
	Subjects				Subjects			
	A	B	C	D	A	B	C	D
37.5° C	20	40	37	28	.1° C	.1° C	.1° C	.1° C
35	70	40	30	97	.1	.1	.1	.1
32.5	65	112	47	83	.1	.1	.1	.1
30	37	48	99	32	.1	.1	.1	.1
27.5	101	61	131	14	.1	.1	.2	.1
25	78	74	25	12	.1	.1	.1	.1
22.5	56	91	13	38	.1	.1	.1	.1
20	31	30	15	19	.1	.1	.1	.1
17.5	22	20	10	63	.1	.1	.1	.1



Graph II. Composite curve constructed from the individual curves of Graph I.



Graph III. Curve showing the difference limina for 40° C., 32.5° C., 27.5° C., and 25° C., under varying conditions of adaptation. The adaptation temperatures are represented on the abscissa and the amount of the difference limen on the ordinate.

Subject A ———————————— difference limen for 40° C.

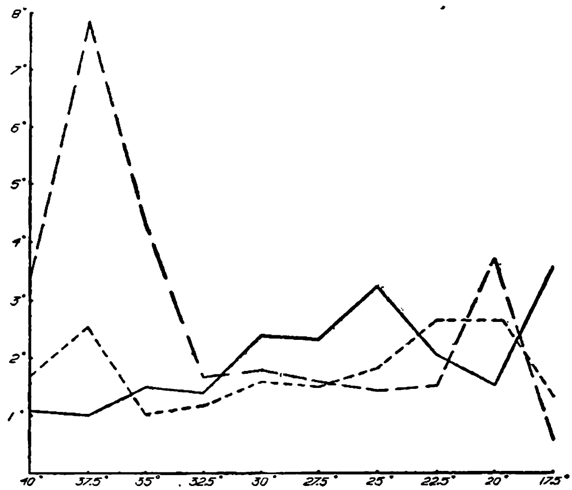
Subject A — — — — — — — — — — — — — — — difference limen for 32.5° C.

Subject C ——— — — ——— — — ——— difference limen for 27.5° C.

Subject A ——— ——— ——— ——— difference limen for 25° C.

TABLE FOR GRAPH III

Adaptation temperature.	Number of tests involved in determining difference limen.				Interval at which the percentage of right cases varied from the standard.			
	Temperature for which difference limen was determined.				Temperature for which difference limen was determined.			
	40° C	32.5° C	27.5° C	25° C	40° C	32.5° C	27.5° C	25° C
40° C	16	65	131	78	.1° C	.1° C	.1° C	.1° C
37.5	23	54	44	36	.1	.1	.1	.1
35	16	38	22	52	.1	.1	.1	.1
32.5	38	26	28	38	.1	.1	.1	.1
30	26	41	34	71	.1	.1	.1	.1
27.5	12	40	42	25	.1	.1	.1	.1
25	25	41	69	33	.1	.1	.2	.1
22.5	24	43	50	62	.2	.1	.1	.1
20	25	53	71	28	.1	.1	.1	.1
17.5	33	29	21	28	.1	.1	.1	.1

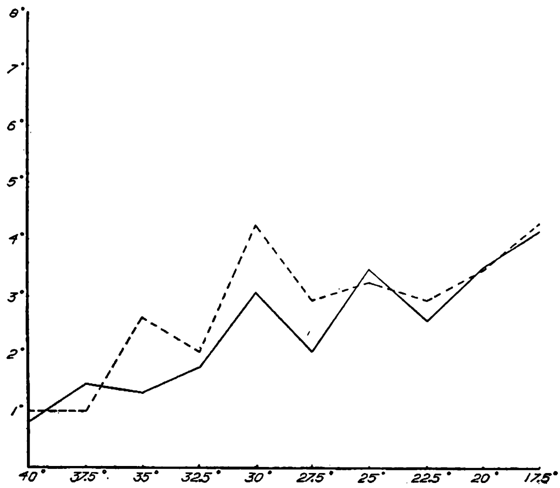


Graph IV. Curve showing difference limen for different temperatures after adaptation to 40° C., to 32.5° C., and to 17.5° C. The temperatures for which difference limina were determined are represented on the abscissa and the amount of the difference limen on the ordinate.

——————————— Adaptation to 40° C.
— — — — — — — — — — Adaptation to 32.5° C.
——— ——— ——— Adaptation to 17.5° C.

TABLE FOR GRAPH IV

Temperature for which difference limen was determined.	Number of tests involved in determining difference limen.			Interval at which the percentage of right cases varied from the standard.		
	Adaptation temperature			Adaptation temperature		
	40°C	32.5°C	17.5°C	40°C	32.5°C	17.5°C
40° C	39	38	57	.1°C	.1°C	.1°C
37.5	40	36	68	.1	.1	.1
35	40	30	52	.1	.1	.1
32.5	112	42	58	.1	.1	.1
30	48	46	16	.1	.1	.1
27.5	61	68	25	.1	.1	.1
25	74	45	33	.1	.1	.1
22.5	91	58	28	.1	.1	.1
20	30	53	46	.1	.1	.1
17.5	20	44	44	.1	.1	.1



Graph V. Curve showing the effect of adaptation to 40° C. on the difference limen compared with that of adaptation to 17.5° C. immediately followed by adaptation to 40° C. The temperatures for which the difference limen was determined are represented on the abscissa and the amount of the difference limen on the ordinate.
Subject D

——————————— Adaptation to 40° C.

— — — — — — — — — — — Adaptation to 17.5° C. immediately followed by adaptation to 40° C.

TABLE FOR GRAPH V

Temperature for which difference limen was determined.	Number of tests involved in determining difference limen.		Interval at which the percentage of right cases varied from the standard.	
	Adaptation to 40° C	Adaptation to 17.5° C. followed by adaptation to 40° C	Adaptation to 40° C	Adaptation to 17.5° C. followed by adaptation to 40° C
40° C	38	19	.1	.1
37.5	20	62	.1	.1
35	97	49	.1	.1
32.5	83	40	.1	.1
30	32	38	.1	.1
27.5	14	51	.1	.1
25	12	56	.1	.1
22.5	38	41	.1	.1
20	19	15	.1	.1
17.5	63	27		

Objective Results

The first group of experiments, the results of which are represented in Graph I, was conducted with all four subjects. The adaptation temperature was constantly at 40° C. and the difference limina were determined for 37.5° C., 35° C., 32.5° C., 30° C., 27.5° C., 25° C., 22.5° C., 20° C., and 17.5° C. The ordinate in each case represents the difference limen in degrees Centigrade. Following the Graphs are tables showing the number of tests involved in determining each difference limen and the interval at which the percentage of right judgments exceeded or fell below the difference limen standard.

The main points to be noted in the curves are their similarity and the fact that there is a very consistent drop at 32.5° C. It should also be noted that although two of the curves drop between 22.5° C. and 20° C. there is a uniform and considerable rise between 20° C. and 17.5° C. There is a rise between 32.5° C. and 30° C. Between 30° C. and 20° C. irregularities occur both in the curves themselves and in their relation to each other although the general contour of the curves is remarkably similar even here. Graph II is the composite curve for the individual curves of Graph I. It brings out more clearly the points noted above.

Graph III represents the results of experiments carried on with two subpects. Subject C left during the college year and we were unable to finish the series begun with him. The curve of his results is comparable with the others of the Graph only in that it shows the same general relations. Because of individual differences in sensitivity no absolute comparisons can be made between it and the others. Each curve in this Graph represents the difference limen for a certain temperature under varying conditions of adaptation. The adaptation temperatures used were 40° C., 37.5° C., 35° C., 32.5° C., 30° C., 27.5° C., 25° C., 22.5° C., 20° C., and 17.5° C. The temperatures for which the limen was determined were 40° C., 32.5° C., 27.5° C., and 25° C.

The curve for the difference limen of 32.5° C. under varying conditions of adaptation is almost a straight line wth the exception of a sudden rise between 20° C. and 17.5° C. The curve for 32.5° C. also shows the smallest difference limen in every instance except with adaptations 40° C., 37.5° C., and 35° C., where the limen for 40° C., is slightly lower and with adaptation 30° C. where the limen for 25° C. is slightly lower. It should be noted that temperatures 25° C. and 40° C. are equidistant in opposite directions on the thermometric scale from 32.5° C. Under the same conditions of adaptation, however, their difference limina do not vary equally from that of 32.5° C. except with 32.5° C. and 20° C., adaptation where they are only .1° C. apart. Moreover the adaptation which gives the point of greatest sensitivity for 25° C. lies two and a half degrees below 32.5° C. and that which gives the point of greatest sensitivity for 40° C. lies two and a half degrees above 32.5° C. The two curves are not, however, uniformly converse. Several of these points are verified in other experiments with different subjects under slightly different conditions and will be pointed out again.

The facts which were so very apparent from this group of experiments, namely, that different conditions of adaptation had little or no effect on the difference limen for 32.5° C.; and that 32.5° C. seemed to be in general the region of greatest sensitivity to temperature differences while changes in either direction on the thermometric scale brought about a decrease of sensitivity with an increased susceptibility to variation under different conditions of adaptaton; these facts seemed to point to 32.5° C. as an adaptation which might furnish a norm for the difference limen for different temperatures which could profitably be compared with the difference limina for these same temperatures obtained under varying conditions of adaptation. Such a series of experiments was performed with subject B and the results are given in Graph IV.

This Graph verifies in an interesting way the observation made on the basis of Graph III that the condition of adaptation has little effect on the difference limen for 32.5° C. Three curves are given; one, the curve of the difference limina for 40° C., 37.5° C., 32.5° C., 30° C., 27.5° C., 25° C., 22.5° C., 20° C., and 17.5° C. with a constant adaptation temperature of 40° C.;

one, the curve of the difference limina for the same temperatures with a constant adaptation of 17.5° C.; and the third is the curve for the difference limina of the same temperatures with a constant adaptation of 32.5° C. The difference limina for 32.5° C. under these conditions lie within .5° C. of each other. The Graph, moreover, demonstrates that this is the only temperature of those used of which this is true since the limina for no other temperature lie so near each other.

It was noted in Graph III that with an adaptation temperature of 32.5° C. the difference limina for 40° C. and 25° C. were only .1° C. apart. In Graph IV the limina for the same temperatures under the some conditions, although greater than those for subject A, are again only .1° C. apart. This is a further verification of the results represented in Graph III.

One of the most interesting points of Graph IV is the converse character of the curves for adaptation to 40° C. and to 17.5° C. They cross close to 32.5° C., to 22.5° C. and again between 17.5° C. and 20° C. The curve for adaptation to 32.5° C. lies between the two except at 22.5° C. where it is above them both and between 27.5° and 35° C. where it lies below them both. In its general shape the curve follows the line of that for adaptation to 17.5° C. rather than for adaptation to 40° C. The same sudden change in the direction of the curves at 20° C. characterizes this as well as the other Graphs.

When we planned the experiment the results of which are shown in Graph V we had in mind the observation of Goldscheider (Physiologie der Hautsinnesnerven. 1898, vol. I, p. 143) to the effect that an adapted cold spot during the time of its recovery from adaptation was not affected by the medium in which it was placed during recovery. It seemed interesting to compare difference limina for 40° C., 37.5° C., 35° C., 32.5° C., 30° C., 27.5° C., 25° C., 22.5° C., 20° C., and 17.5° C. after an adaptation temperature of 40° C. with the difference limina for these same temperatures after an adaptation temperature of 17.5° C. immediately succeeded by adaptation to 40° C. If adaptation had a physiological basis involving different sets of endorgans, as Goldscheider's observation might lead one to infer, then adaptation to 40° C. might conceivably take place before the effect of adaptation to 17.5° C. had disappeared and such an experiment would give us the effect of adaptation to both extremes to compare with that for the one extreme.

This experiment was carried on with subject D who reported that immediately on putting the hands into 40° C. after 17.5° C. scarcely any warmth was felt but that the warm sensation rapidly increased in intensity to a very warm and sometimes to a hot sensation and that the course of the adaptation process after this was as usual with 40° C. The time of adaptation to 40° C. did not seem to be affected.

The results of this experiment were rather unexpected. The two curves are practically coincident except between 35° C. and 27.5° C. Here the curve for the double adaptation is noticeably higher than that for single adaptation except at 32.5° C. where it drops close to the latter, again verifying the fact that conditions of adaptation have little effect on the difference limen for 32.5° C.

The results on the whole confirm the conclusion, deducible from the observations of other investigators in this field, that the difference limen for a given temperature is likely to vary with the variation of the preceding adaptation temperature. There are exceptions which will be discussed later.

The only instance in which we have approximated a duplication of conditions is the work of Nothnagel[1], in which he obtained the difference limina on the hand for temperatures between 49° C. and 7° C. with the hand adapted at ordinary room temperature and with skin temperature between 33° C. and 36° C. This series is roughly comparable to our curve for difference limina between 40° C. and 17.5° C. with an adaptation temperature of 32.5° C. (Graph IV). He found the finest discrimination between 27° C. and 33° C. We find it occurring at 35° C. and slightly less fine discrimination occurring as low as 25° C. We also find a slow rise for temperatures below 27.5° C. as he did but he does not find the sudden drop that occurs in our curve at 17.5° C.

[1] Nothnagel, H., Beiträge zur Physiologie und Pathologie des Temperatursinns. Deutsch. Archiv. f. Klin. Med. II, 1867, pp. 284-299.

CONCLUSION

The theoretical discussions in the temperature field have centered in the past about the stimulus for the sensation of temperature. Briefly, the views advanced are: the Hering[1] view that the absolute temperature of the endorgan or skin is the determinant of the temperature sensation; and the Weber[2] view that change involving rising or sinking of the skin temperature is felt as warm or cold. The latter is sometimes restated in terms of the direction of the warm stream to or from the body. If the temperature of the skin were rising the direction of the warm stream would always be toward the body and away from it if the skin temperature were falling. Both of these views have been subject to modification but have persisted in essentially the same form throughout the literature. Both of them encountered the difficulty that we are sometimes not conscious of temperature sensation whereas in terms of the theories we should always be conscious of some sensation of temperature. If the sensation depended on the absolute temperature of the skin there is obviously never a moment when the skin is without absolute temperature. Similarly if the sensation depended on change of skin temperature the circulation of the blood and the exigencies of the environment cause a constant interchange of heat between the organism and the atmosphere or other objects as well as a constantly fluctuating skin temperature. No one who has had any experience with mechanical thermostats can believe that a living organism is ever in a condition of thermometric equilibrium for an appreciable interval.

Both views meet this difficulty with a concept which has come to be known as the "physiological zero." This is the name given to a physiological state which gives rise to no temperature sensations but variation from which will give rise to temperature sensations whose quality and intensity depend on the amount and

[1] Handb. der Physiol. III, 2, pp. 415-439 (1880).
[2] Wagner's Handwb. d. Physiol., V. III, 2, p. 481 (1846).

direction of the variation. From Hering's point of view the physiological zero is the result of an absolute skin temperature which has persisted long enough to cease to give temperature stimulation. A change of the absolute skin temperature to another above or below this point will result in a sensation of warm or cold. If this new temperature persists long enough the temperature sensation will cease and a new physiological zero will have been established. From his point of view adaptation is the establishing of such a physiological zero.

From the Weber point of view the physiological zero corresponds to any relatively stable skin temperature following upon a period of change. With the cessation of change the temperature sensation ceases, a physiological condition giving no temperature sensation is set up, and any succeeding change in either direction will give rise to a temperature sensation which will be cold or warm according to whether the change is down or up from the last physiological zero.

No one who surveys the accumulation of facts in the temperature field with either of these views in mind can fail to be struck with the fact that in either case there is an enormous proportion of contradictions and inconsistencies to the number of facts known. No sooner do we begin to state some concrete problem in the terms these views have made current than we find ourselves involved in ambiguous and self-contradictory statements. Part of this difficulty it seems may be avoided in the statement of the present problem by drawing a sharp distinction, as is done in stating problems in other sensory fields, between the objective conditions accompanying the sensation and the physiological conditions accompanying and determining the setting up of the impulse in the nerve leading from the endorgan.

The physicists tell us that heat is an interchange of energy between two bodies. It seems simple in that case to conceive of the temperature of the skin rising and falling as it receives or gives up energy to its environment and this change in temperature to be accompanied in consciousness by temperature sensations. But so simple a statement is entirely inadequate to describe the situation. The skin itself is made up of living cells each one generating heat. The organism as a whole is generating heat which is carried to the skin by the blood. Conditions of environment differ constantly over the surface of the organism, both in regard to temperature and conductivity, vaso-motor conditions vary the blood supply constantly, and nutritive conditions also have their effect. The statement in mathematical terms of the heat potential of any given area of skin at any given moment would be a superhuman task involving all the factors already mentioned as well as that of relative mass of all the objects concerned, and even were it accomplished we should still be in the dark as to the physiological process by which the nervous structure of the endorgan is modified in the course of the exchange of heat or what relation this process bears to the thermometric scale. Were these different factors in the situation understood, the seemingly contradictory facts of temperature sensation could doubtless be explained in terms of them. But the time, when even a beginning at such an explanation can be made, is so far distant that it seems profitable to try to find other terms in which to describe temperature phenomena for the time being.

Suppose a skin area is placed in a medium maintaining a constant temperature of 30° C. There will be a period of temperature sensation which will shortly pass away and thereafter as long as the environmental temperature is kept constant there will be no temperature sensation. It is of course possible that physiological changes within the organism will so change the relation between environment and organism that temperature sensations will ensue but this factor can be minimized under experimental conditions and since it is a factor of which we can have no objective measurement it must be so eliminated. If the environment is now changed to 40° C. a temperature sensation will inevitably ensue. But if this new temperature is kept constant in its turn, the sensation will cease and no new sensation will occur until another change in the environment takes place. The situation may then be stated in this way. We have on the conscious side a period of no sensation followed by a sensation and again by another period of no sensation. Objectively we have a constant temperature of 30° C. followed by a change of ten degrees and another constant temperature. The objective change in temperature is coexistent in time with the appearance of the sensation and with such a change a sensation will always normally appear. The temperature of the skin and in turn that of the endorgan may have changed ten degrees or five or next to none. We have no means of knowing exactly. Nor have we any means of knowing how the condition of the endorgan differs in the case of the second constant temperature from that of the first. We have no right to use such a difference as a term in describing the phenomenon. As the only available criterion of the intensity of the sensation we have the subjective evidence of the observer. All that we can say with definiteness is that change in temperature of the environment is accompanied by sensations of temperature and that under a constant temperature condition of the environment sensations of temperature cease. Adaptation to temperature, stated in these terms, will mean absence of temperature sensations and a constant environmental temperature. The amount of change and duration of constancy of the environmental temperature happen to be things we can control experimentally. Therefore they are comparatively safe terms to use for the present.

The point which the results of the present experiment bring out most clearly is the fact that the explanation of adaptation by the conception of a physiological zero in the form of an actual physiological state shifting up and down with external conditions much as the mercury shifts up and down in the thermometer and determining the quality and intensity of the ensuing sensation, is not compatible with the facts. If such a physiological phenomenon did occur we would expect it to have an effect on the difference limina determined with different adaptation temperatures. That is, if we found a difference limen of 1° C. at 40° C. with an adaptation of 30° C. we should expect to find a smaller limen at 40° C. with an adaptation of 35° C. for we have brought the physiological zero 5° C. nearer to 40° C. and, in the old terms, 40° C. would give less variation from the physiological zero, the sensation would be less intense and difference more easily perceived. And a glance at the graphs will show that we find something quite like this. But if this change in difference limen were the effect of an actual physiological condition, we should find some evidence of shift in the difference limina all through the thermometric scale for we have shifted the physiological zero with relation to all temperatures. Instead we find a certain definite point on the thermometric scale where conditions of adaptation have practically no effect whatever. This is 32.5° C., the point of greatest sensitivity to temperature difference. The resistance of sensitivity at this point to any and all conditions is brought out in all the curves. This makes one dubious of the shifting physiological zero. The curves do seem to show, however, that there is a point on the thermometric scale which may be taken as a norm where shift in external temperature is most readily recognized and from which sensitivity to change in temperature decreases in either direction. This temperature (32.5° C.) is very close to 32° C., which is given by Benedict and Slack[1] as normal skin temperature. It is to be regretted that 32° C. was not one of the temperatures used but the temperatures were chosen rather arbitrarily at the beginning of the experiment, there being nothing particularly to guide a choice. We shall refer to this temperature as skin temperature since the term "physiological zero" has acquired such a distinctive connotation.

From a biological point of view the persistence of skin temperature, as a more or less constant basis for appreciating variation of temperature, is a much more possible conception than the older one of a shifting physiological zero. If an organism, in whose life processes the temperature factor were vital, should move into a temperature warmer than normal, and the physiological zero should then move up so that an increase of warmth were only slightly sensed, and this in turn should produce a higher physiological zero, there would be nothing to prevent the organism moving on to its destruction. Such a psysiological zero in any event would never be useful and might be distinctly harmful.

[3] Benedict, F. G., and Slack, E. F., A Comparative Study of Temperature Fluctuations in Different Parts of the Body. From the Nutrition Laboratory of the Carnegie Institution of Washington. 1911.

The problem remains of explaining the varying effects of different adaptation conditions on temperatures above and below skin temperature. Suppose a subject is in a state of adaptation to skin temperature and the objective temperature is raised to 35° C, The subject appreciates it as warmer than skin temperature, but this objective temperature again remains constant and the temperature sensation disappears. Shortly the objective temperature is raised again to 40° C. This again is judged warmer than skin temperature but this time the judgment is made in terms of the last increase from skin temperature, that is, it is a genuine perception. It is very evident that any such judgment would be modified by the last previous sensation and would vary as it varied. Such processes, involving the use of past experience, where the whole mechanism of comparison and judgment has dropped from consciousness leaving only the final result registered in consciousness as a unit, are frequent in all the other senses and there is no reason to suppose that such a process should not have been built up in the temperature sense which is one of the oldest. That it has never overtly appeared in normal human consciousness is no more an argument against it than it is against the perceptual character of the processes involving visual space. It is of great biological importance that such a process should be built up for, as an organism passes through varying temperatures, it will have to know not only that each succeeding temperature varies from its normal habitat but whether it varies more or less than the last one it experienced. Else how would it know it was getting nearer to or farther from where it ought to be?

We have somewhat complicated the situation in our experiment by making it necessary for the subject to judge between two temperatures both varying from skin temperature and to do this in terms of a third (the adaptation temperature), which gave rise to the sensation immediately preceding the adaptation experience and which also varied from skin temperature in most cases. Occasionally we presented him with two temperatures one of which was skin temperature itself. The results (see Graph III) show that under these circumstances the judgment not only improved but that for all such experiments the judgment was practically the same.

We should expect that, if this is a true description of the situation, we would find that adaptation to 40° C., for instance, would give a rather better discriminative judgment as the discriminated temperatures approached 32.5° C. from 40° C. since they would be judged as varying from skin temperature less than 40° C. while beyond the skin temperature in the other direction the 40° C. adaptation would only prove confusing. A glance at the curves will show that this is in general the case. The curve on Graph IV, for instance, which shows the difference limina for different temperatures with an adaptation temperature of 17.5° C., is noticeably low and uniform between 22.5° C. and 32.5° C. where it begins to rise rapidly. We should also expect to find that if an adaptation temperature of 40° C. were used the temperatures between 40° C. and skin temperature would seem somewhat less intensive and the discrimination judgment therefore finer than if an adaptation temperature of 32.5° C. were used. The same thing should hold on the other side of skin temperature if an adaptation temperature of 17.5° C. were compared with that of 32.5° C. The curves of Graph IV substantiate this in the main although rather more clearly for 40° C. adaptation than for 17.5° C. adaptation. Another effect should be that the influence of an adaptation temperature on the discrimination between temperatures on the opposite side of the skin temperature would vary rather more in the case of temperatures near the skin temperature than of those at a distance since it would probably have very little effect on those at a distance, while it would effect more or less those near by. This too proves to be the case as the curves indicate. The last curve (Graph V) is particularly striking in this respect for the extreme cold adaptation temperature preceding the extreme warm adaptation temperature has proved confusing only for the temperatures near skin temperature.

The factor, which influences the sensation ensuing on a period of adaptation to temperature, seems to be, not the adaptation experience itself, but the sensation immediately preceding the adaptation experience.

It may be offered as an objection to the present statement of the adaptation situation that one may get a cool sensation from 35° C. for instance, after adaptation to 38° C. This may be explained as an illusion of the kind which is always found in connection with this type of perceptual process. The temperature 35° C. is judged as varying from skin temperature but so much less so than 38° C. that it is shunted over the line and judged as varying in the opposite direction. The fact that this phenomenon is possible only within certain limits on either side of skin temperature and that these limits may be somewhat extended by introducing the contrast effect as in the experiment in which one hand is plunged into cold water, the other into warm and then both into lukewarm water, is a further indication that it belongs to the illusion type of process.

Since the experiments of Goldsheider and von Frey on the localization of warm and cold spots, it has been generally held that there are separate systems of endorgans for warm and cold sensations. The recent experiments of Head, resulting in a division of cutaneous sensations into epicritic and protopathic have suggested the possibility of four systems of endorgans for temperature sensations. The difficulties of making the physiological zero concept fit such a multiplicity of endorgan systems are obvious. The concept, itself, conceived primarily to explain the adaptation phenomenon, has failed signally to make itself compatible with the facts involved in adaptation under the present experimental conditions. When these facts, moreover, are stated in terms of objective environmental conditions on the one hand and of conscious processes on the other hand any such explanation as the physiological zero becomes needless. That is to say, there seems to be no more reason to suppose that a physiological condition accompanying a state of no-temperature-sensation should affect the quality and intensity of the ensuing temperature sensation than to suppose that a physiological condition accompanying a state of no-pressure-sensation should affect the quality and intensity of the ensuing pressure sensation. Such a supposition would differentiate the temperature sensation from all other sensory fields for in other sensory fields this is true only in the case of a fatigued endorgan and we have already quoted von Frey to the effect that the state of no-temperature-sensation cannot be due to fatigue. Since we can find no parallel for the physiological zero concept in other sensory fields, since it does not fit the facts in the temperature field, and since the facts it attempted to explain may be explained without it, the concept seems untenable.

When the experiment was first undertaken it was thought possible that the results might shed light on the applicability of the Weber Fechner law in the temperature field. If the proferred interpretation of the results is correct, under the conditions of the experiment the only curve which could bear on the question is that for adaptation temperature 32.5° C. in Graph IV. This curve is not in acordance with the Weber Fechner law but it is only one curve for only one subject and no conclusions can be drawn on such slight evidence.

The experiments were not of a nature to throw any light on the duality of endorgans for the temperature series, although the fact that below 20° C. the character of the discriminative judgment often undergoes a marked change, is suggestive. In this connection we may draw attention to the fact that Holm's[4] results for duration of temperature sensations before complete adaptation, show a sudden increase in mean variation and length of adaptation time as the adaptation temperature falls below 20° C.

We may add, in closing, that this is not an attempt to burden the world with a new temperature theory. It is an effort to state the problem in terms which may be used to describe two or more facts without automatically setting the facts by the ears.

[4] Holm, K. J., Die Dauer der Temperaturempfindungen bei constanter Reiztemperatur. Skand. Archiv. f. Physiol., vol. 14, 1903, pp. 242-248.