THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Gregor Benjamin Pirsch for the degree of Master of Science. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

Royal N. Chapman
Chairman

Tom A. Riley

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May 28 1921

THE UNIVERSITY OF MINNESOTA

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Report

of

Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given Gregor Benjamin Pirsch final oral examination for the degree of Master of Science . We recommend that the degree of Master of Science be conferred upon the candidate.

Minneapolis, Minnesota

May 28 1921

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A Study of the Temperature of the Individual Bee.

A Thesis

Presented to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the Degree of Master of Science.

by

Gregor Benjamin Pirsch

June 1921.

Contents.

Introduction.

From the standpoint of temperature there are two classes in the animal kingdom, the warm and the cold blooded animals. That cold blooded animals have practically the same temperature as that of the surrounding medium was shown among others by Rogers and Lewis (1916). Phillips and Demuth (1914) and others found that bees, essentially cold blooded animals, were capable of regulating their temperature when in a colony by increasing the temperature of the colony when the air temperature went down and lowering the temperature of the colony when the air temperature went up. More observations have been made on the bee colony than on the individual bee itself. Since Phillips and Demuth have shown that the colony, which is composed of a large number of individuals, acts very much as a warm blooded animal does, the temperature of the individual must be of great importance. If this were not true it would be difficult to understand how a colony of individuals could control its temperature. For this reason and because of the wide variation in the results obtained by previous writers, this problem was chosen for study.

In a review of the literature it was found that previous workers had based the results of their observations on a few individuals while the results of this paper are based on the readings of eight hundred and twenty-eight bees. The methods and results of the previous workers are given in the following review of the literature.

Review of Literature.

*Hausmann (1830) was the first to establish the temperature of an individual insect. He placed a Sphinx convolvuli together with a small thermometer in a glass receptacle, the air temperature of which was 17°R. (21.25°C.). After half an hour the temperature had risen to 19°R. (23.75°C.) and soon after fell to 17°R. Experiments with Carabus hortensis gave the same results.

Davy (1826) was the first to give the internal temperature of an insect. An incision was made in the body and the bulb of a very small mercurial thermometer was inserted. He obtained the following results.

	Air temperature in degrees C.	Insect temperature in degrees C.
Blatta orientalis	28.3	23.9
" "	23.3	23.9
Gryillidae	16.7	22.5
Vespidae	23.9	24.4
"	24.3	25.0
Lampyridae	22.8	23.0
"	26.6	25.8

Nobili and Melloni (1831) were the first to use electric methods in determining the temperature of insects. They used the electromotive force developed when the junction of wires of different metals of a common circuit are at different temperatures. They used bismuth and antimony wires. One

* According to Newport (1837).

of the couples of the wires was in contact with the insect body, the other couple was free. They made a series of experiments in the temperature of larvae, pupae, and adult butterflies. Their conclusion was that the temperature of the insect was higher than that of the surrounding air.

*Mussehl (1836) ascertained that single bees became motionless at +5°R. (6.25°C.) while they did not suffer from cold in the colony with the temperature of the hive at -1°R. (-1.25°C.).

Newport (1837) used a thermometer of small calibre with a cylindrical bulb about one half inch in length. The thermometer was placed beneath, and as completely covered by the abdomen of the insect as possible. A second thermometer which had been carefully compared to the first was placed at the same level with and a short distance from the first one. The temperature of the insect was taken on the exterior and was always lower than that of the interior. He stated that the internal temperature was seldom if ever more than a degree and a half or at the most two degrees above the external temperature. The following are some of his results showing the difference between the air temperature and the external temperature of the insect:

	Temperature of air in degrees F.	Body temperature in degrees F.	Temperature difference in degrees F.
1. Bombus terrestris	66.9	73.4	6.5
2. " "	66.9	76.2	9.3

* According to Bachmetjew (1901).

	Temperature of air in degrees F.	Body temperature in degrees F.	Temperature difference in degrees F.
3. Bombus terrestris	66.9	73.4	6.5
4. " "	69.4	76.2	6.8
5. " "	68.0	77.5	9.5
6. " lapidarius	68.0	71.5	3.5

At the time of taking the above readings the insects were in an excited condition.

Dutrochet (1840) used a thermocouple made by soldering an iron and copper wire together. He placed one couple in the body of the insect and the other couple in the body of a dead insect of the same species or in paper. He fastened several bees to a hive by means of a thread. One couple was placed five millemeters deep in the body of the bee, the other couple was wrapped in paper to protect it from radiation. The air temperature was constant for four hours (19.2°C.). This experiment showed that the temperature of the insect was 0.18°C. lower than that of the surrounding air. The bees were next placed in a bell jar with the air dampened. They then had a temperature 0.18°C. higher than the air temperature.

Experiments with Bombus hortorum were also performed. The thermocouple was not placed in the body but merely placed against it. The bee was then wrapped up in a piece of gauze which caused it to become very excited. Under these conditions the temperature was 0.5°C. higher than that of the surrounding air. As the bee became quiet its temperature was 0.03°C. lower than the air temperature. Dutrochet found that

insects when active had a temperature higher than the surrounding air, when inactive a temperature that corresponded to the surrounding air.

*Dzierzon (1856) observed that bees became motionless at 5°R. (6.25°C.).

*Dönhoff (1857) placed two hundred bees in a glass container the temperature of which was 22.5°C. In a short time the temperature had risen to 34.4°C. He also pressed an individual bee against a thermometer and found it to have a temperature of 15/16°C. higher than that of the air. He concluded that the difference in temperature between the bee and the surrounding air was greater when the air temperature was low and less when the air temperature was high.

*Berlepsch (1860) found that the bees left the hive and flew into the fields when the temperature was 12°R. (15°C.) in the shade.

* Schönfeld (1866) placed one hundred bees in a water glass which was perfectly dry. A piece of old dried wax was attached to the cover of the glass in which there was a hole for the insertion of the thermometer. A small board was placed in the bottom of the glass on which the thermometer rested. The entire apparatus was placed on a cook stove. After three hours and twenty-five minutes the thermometer had risen from 10°R. (18.75°C.) to 31.5°R. (39.3°C.). All of the bees with the exception of five were found standing on the wax. One bee commenced to fan as the temperature reached 32.7°R. (40.8°C.) and at 36°R. (45.0°C.) eighty bees fell to the bottom of the glass

* According to Bachmetjew (1901).

and died. Sixteen bees were still living at 46°R. (57.5°C.) and when the cover was removed they flew out. The experiment was repeated and two bees withstood the temperature of 48.2°R. (60.2°C.) and flew away when the glass was opened.

*Girard (1869) carried on several experiments on insect temperature and found that the bumble bee when in lack of honey had a lower temperature; that Bombus terrestris was twice as warm in the spring as it was in the fall. He concluded also that Hymenoptera had a higher temperature than the surrounding air but a significantly lower temperature than that of the Lepidoptera and Diptera.

Donhoff (1872) observed that bees soon died at -1.5°C. when placed in frozen ground.

*Dzierzon (1878) ascertained that bees soon died when brought to the temperature of 5°R. (6.25°C.).

*Molin (1880) found that bees became motionless at 5°R. (6.25°C.) and that at 7°R. (8.75°C.) they cleaned themselves and carried water. They left the hive and flew into the field at 12°R. (15°C.).

* Vogel (1880), Rodel (1886) and *Andriaschew (1890) observed that bees became motionless at 5°R. (6.25°C.).

*Koschewnikow (1895) noted that bees kept at a temperature between 0° and +1°R. (0° to 1.25°C.) for ten and one half hours lived. Other bees that were motionless for thirty hours at a temperature of -1°R. (-1.25°C.)also survived. After the bees were kept at -2°R. (-2.5°C.) for fifty minutes they died.

* According to Bachmetjew (1901).

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In his work on maximum temperature he concluded that:

1. There was a range of 9°R. (11.25°C.) in the fatal temperature of bees.
2. Dryness and dampness had no effect on bees in high temperature.
3. Workers and drones became very excited when the temperature was above 30°R. (37.5°C.).
4. The lowest temperature at which workers died was 35°R. (43.75°C.) while the drones died at 30°R. (37.5°C.).
5. The highest temperature which the bees could withstand was 44°R. (55°C.).
6. The workers immediately upon hatching showed a sensitiveness to heat, none surviving more than 39°R. (48.75°C.).
7. Still younger bees with the chitin less hard but apparently well formed were in contrast to the above mentioned because they were more capable of withstanding a higher temperature. They died at 52° to 53°R. (65°C.). The explanation of the above phenomenon appears to lie in the fact that their bodies contain considerable moisture and that they did not move.
8. Upon bringing the bees immediately into high temperature he observed that the period which passes between the time of inserting the bees and their death became shorter with increases in temperature.

In the following review of the experiment no statement was made as to whether or not the figures given were the actual temperatures of the insects.

Temperature to which bees were exposed.	Period of time of exposure.	Temperature of bees at death.
44°R.	2 min.	45°R.
45°R.	2 " 10 sec.	46°R.
46°R.	2 " 5 "	46.75°R.
47°R.	2 " 15 "	48°R.
54°R.	1 " 30 "	55°R.
55°R.	1 " 10 "	55.5°R.
55.5°R.	1 " 10 "	56°R.
56°R.	1 " 10 "	56.25°R.
57°R.	45 "	57.5°R.

Bachmetjew (1899) performed several experiments on the temperature of insects, especially Lepidoptera. He used a thermocouple made by soldering steel and manganese wires together. Both wires were connected to a galvanometer, one directly and the second after it had passed through a commutator. The wires were insulated by passing them through small glass tubes. Butterflies were placed on the couple and from many experiments Bachmetjew concluded that:

When the body temperature reached 39°C. the insect became very active and died at 46 to 47°C.

When the air temperature was lowered the body temperature of the insect was lowered to approximately -15°C.; there was then a rebound in the body temperature from about -15°C. to about -1°C. When the temperature of the body began again to fall the insect died when the low point (-15°C.) was reached the second time.

That different species of insects have a different critical

temperature.

Bachmetjew (1901) made a general study of insect temperature in which he covered the work previously done on this subject.

Brunnich (1919) made a study of the temperature of the bee body and the bee brood. He used a thermocouple made by soldering a copper and platinum wire together, forming the warm junction of the couple. To the free end of the platinum wire, which was only a few centimeters in length, he soldered another copper wire. This second union acted as the cold junction of the couple. He also used a telescope reading galvanometer which he stated was not sensitive enough since fifteen seconds were required before the maximum reading was reached. The bees were greatly weakened by piercing with this rough thermocouple and soon died. He found that the body temperature of adult workers went as high as 39.6°C. while that of the drones went as high as 48.4°C. The results, however, gave no indication of uniformity because some individuals gave high temperatures while others, under the same conditions, gave low temperatures.

Since platinum is a good conductor of heat, there is great danger in having the warm and cold junctions separated by a piece of wire only a few centimeters in length. In piercing the bee the temperature of its body or the handling of the wires, if held near the second couple, is likely to increase the temperature of that couple, thereby introducing an error in the readings. The increasing of the temperature of the second couple was undoubtedly the cause of the wide range in the body temperatures cited by Brunnich in his paper.

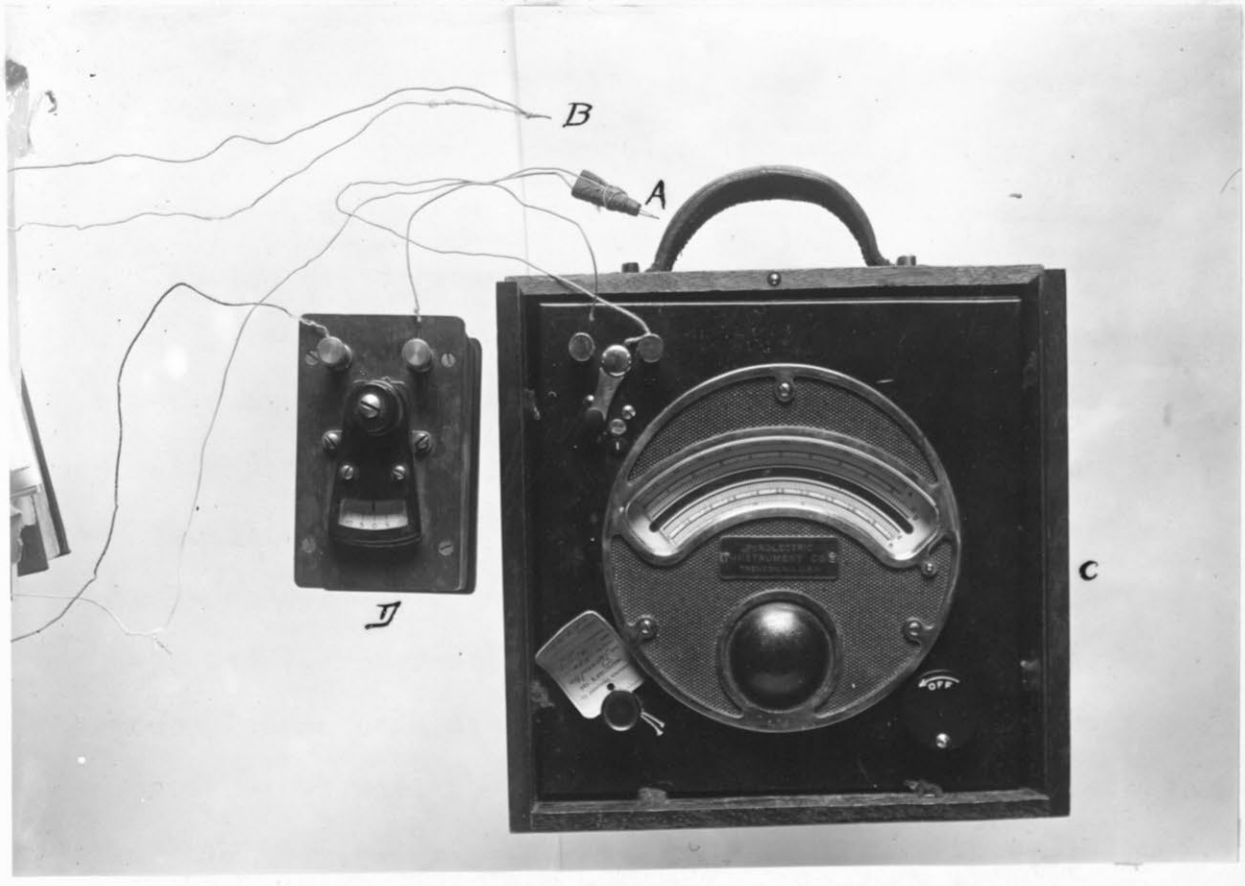

Plate I.

A. Warm junction of the thermocouple.

B. Cold junction of the thermocouple.

C. Pyrovolter.

D. Galvanometer.

Methods.

The piercing of bees in the following experiment was done with a thermocouple (Plate I-A) made by soldering number 20 double cotton-covered copper and constantan (a copper-nickle alloy) wires together. The wires were drawn to a fine point before soldering by inserting the ends in concentrated nitric acid and slowly withdrawing them. This process was repeated until the wires obtained the desired points. The tapered ends were then soldered together and the surplus solder filed off. A piece of cork was inserted between the two wires near their junction to strengthen the couple and aid in the handling of it.

The readings were made with the aid of a pyrovolter (Plate I-C), galvanometer (Plate I-D), and the bee was pierced with a thermocouple of which the cold junction (Plate I-B) was placed in a thermos bottle filled with ice and water to keep it at $0^{o}C$. A Northrup pyrovolter and a Leeds-Northrup outside galvanometer, to aid in the setting of the zero point, were used. By having one junction of the thermocouple in ice and water the resulting reading on the pyrovolter was the actual temperature of the bee.

One of the rooms in a cold storage plant was used for the low temperature, $5.5^{o}C$. For the room temperature, readings were made in the laboratory. Temperature readings for $27^{o}C.$, $30.5^{o}C.$, $35^{o}C.$, $39.5^{o}C.$, $44^{o}C.$, $52^{o}C.$, and $58^{o}C.$ were made in a temperature box in which the heat was regulated by a series of lights. The temperature box was made by placing insulite on the outside of a box 34" X 35" X 52" the inside of which was lined

with asbestos paper. There were two ventilating holes, one in the side near the bottom, the other in the top of the box.

At all temperatures the bees were allowed at least ten minutes to become adapted to the surrounding air before the first of the group was pierced. When readings were made at 52° and 58°C. it was found that the bees exposed to this high temperature for about thirty minutes were dead. The bees were placed in the temperature box, at this high temperature, in groups varying from five to eight bees per group and exposed to the temperature for ten minutes before any were pierced. The groups were placed in the box while its temperature was about that of the room. The lights were then turned on and after the temperature had reached 52° or 58°C. and remained constant for ten minutes the temperature readings were made.

Only Italian bees were used in this experiment. All bees with the exception of those used for the purpose of the check (Table XI) were taken from the same hive which was in winter condition. On November 25th this hive along with ninety others was placed in a room in a cold storage plant which maintained a temperature of about 7° to 7.5°C. throughout the experiment. Those used for the check were taken from different hives and placed in groups, no two bees from the same hive in a group. A different group was used for each of the points on the curve.

When taken from the hive the bees were placed in individual cages which allowed each bee the space of 1/4" X 1/4" X 5/8". The cage was made from a block of wood 3/4" X 3/4"

X 2" with a 1/4" X 1/4" groove in one surface. Cotton thread was used to wind around the block to prevent the escape of the bee. The thread also aided in piercing as it permitted full view of the bee and eliminated the possibility of cross currents which might occur when using a wire screen to cover the groove.

All piercing was done in the thorax since there are no large air sacs in this region. It did not make any difference whether the dorsal or ventral surface was pierced as shown in Tables I and II. By using a fine thermocouple there was no noticeable bad effect on the bees such as Brunnich (1919) described in his paper. Several bees which were pierced, placed in a cage and fed lived as long as bees not pierced and kept under the same conditions. Upon piercing these bees the second time the same differences, between the body temperature and that of the air, were obtained as at the first piercing.

All thermocouples used in the experiment were carefully compared to the mercurial thermometer used by taking ten readings of the temperature of the air before any of the bees were pierced. The following is an example of the results obtained in such a comparison:

Air temperature (mercurial thermometer) 24°C.

Air temperature (thermocouple) 23.5°C., 24°C., 24°C., 24°C., 24°C., 24°C., 23.5°C., 24°C., 24°C., 24°C.

Results.

The results of the readings are grouped in the following tables.

Table I.

Air temperature 5.5°C.

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
1	11#'	19	10.5*'
2	11*'	20	10.5#'
3	12*'	21	10*'
4	11*'	22	9*
5	10.5*'	23	9.5*
6	11*	24	9.5#
7	10#	25	10*
8	12*	26	10#
9	11#	27	10*
10	11#	28	10#
11	11.5*	29	11*
12	14*	30	9.5*
13	12#	31	8.5*'
14	11*	32	9#'
15	11#	33	9#'
16	10.5#'	34	9.5#'
17	11*'	35	9.5#'
18	11*'	36	9*'

* Dorsal surface pierced.
\# Ventral surface pierced.
' Active when pierced.

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Table I (cont'd.)

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
37	9*'	59	10.5*
38	9*	60	10*
39	9.5#	61	10.5*'
40	9*	62	13.5*'
41	10#	63	10.5*'
42	9#	64	10#'
43	9.5*	65	9*'
44	9.5*	66	9.5#'
45	9.5#	67	9.5#
46	10#'	68	10#
47	10.5#'	69	9*
48	9.5#'	70	9.5#'
49	9#'	71	13.5#'
50	10.5#'	72	11#
51	10#	73	10#
52	9#	74	10*
53	9*	75	9*
54	9*	76	10*'
55	9.5*	77	10*'
56	10*	78	9*'
57	10.5*	79	10*'
58	10*	80	10#'

* Dorsal surface pierced.
\# Ventral surface pierced.
' Active when pierced.

Table I (cont'd.)

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
81	10#'	91	9.5*'
82	9.5#	92	10#'
83	10.5#	93	9*'
84	10.5#	94	9.5*'
85	10#	95	9*'
86	11.5*	96	9.5#'
87	11*	97	9.5*
88	11*	98	9*
89	10.5#	99	9.5*
90	10.5*	100	9.5#

Average temperature 10.2° C.

Difference between body temperature and air temperature 4.6° C.

* Dorsal surface pierced.
\# Ventral surface pierced.
' Active when pierced.

Table II.

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
	21.5°C.**		20°C.**
1	25.5#	21	25.5#
2	25*	22	25#
3	25.5*	23	24#
4	24.5#	24	26.5#
5	25*	25	25#
6	24.5#	26	23.5#
7	25#	27	27#
8	26#	28	26*
9	26#	29	24*
10	25.5#	30	23#
	19.5°C.**		22.5°C.**
11	23.5#	31	26#
12	24#	32	26.5#
13	23.5#	33	26.5#
14	22.5*	34	28#
15	24*	35	30#
16	24.5#	36	26.5#
17	26#	37	29*
18	24.5*	38	28#
19	24#	39	27.5#
20	22*	40	26*

** Air temperature at which bees were pierced.
* Dorsal surface pierced.
# Ventral surface pierced.

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Table II (cont'd)

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
	24° C.**		24° C.**
41	28*	61	28#
42	29#	62	29.5#
43	29#	63	31*
44	27.5#	64	29*
45	28#	65	27.5#
46	27.5*	66	27.5#
47	28*	67	29#
48	28.5#	68	27*
49	28#	69	28#
50	28#	70	26*
	22° C.**		20° C.**
51	29*	71	25#
52	26.5#	72	24.5#
53	29#	73	25*
54	27*	74	24*
55	27.5*	75	25*
56	26#	76	24#
57	28#	77	24*
58	28*	78	25*
59	27#	79	24.5#
60	26#	80	24#

** Air temperature at which bees were pierced.
* Dorsal surface pierced.
# Ventral surface pierced.

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Table II (cont'd.)

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
	20° C.**		19.5° C.**
81	23.5#	91	24#
82	24#	92	24*
83	24.5#	93	24#
84	24#	94	23#
85	25#	95	24*
	19.5° C.**	96	24*
86	23.5#	97	24#
87	24#	98	24.5#
88	26*	99	23.5*
89	25.5#	100	23#
90	25*		

Average temperature 25.8° C.

Difference between body and air temperature 4.4° C.

Average air temperature 21.4° C.

** Air temperature at which bees were pierced.
* Dorsal surface pierced.
# Ventral surface pierced.

Table III.

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
1	29	23	29
2	29	24	29
3	29	25	29.5
4	29.5	26	29.5
5	28.5	27	29.5
6	29.5	28	29
7	29	29	29.5
8	29	30	29.5
9	28.5	31	29.5
10	30	32	29.5
11	29	33	39
12	28.5	34	29
13	29.5	35	28.5
14	29	36	30
15	29.5	37	29
16	29	38	29
17	29.5	39	29
18	29	40	29
19	28.5	41	29
20	29	42	29
21	29.5	43	29
22	29.5	44	28.5

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Table III (cont'd.)

No. of bee.	Body temperature in degrees C.
45	28.5
46	29
47	28.5
48	29.5
49	29
50	29
51	29
52	29.5
53	29
54	29

Average body temperature 29.1° C.

Average air temperature 27° C.

Difference between body and air temperature 2.1° C.

Table IV.

Air temperature 30.5° C.

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
1	31.1	23	31
2	31.5	24	32
3	32	25	32.5
4	30.5	26	32
5	30.5	27	32.5
6	32	28	32
7	32	29	32
8	32	30	31.5
9	31.5	31	32
10	32	32	32.5
11	32	33	32
12	32	34	32
13	32	35	32
14	34	36	33
15	31.5	37	31.5
16	32	38	32
17	34	39	32
18	32.5	40	32
19	31.5	41	32
20	32	42	31
21	31.5	43	32.5
22	32	44	31.5

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Table IV (cont'd.).

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
45	32	67	31.5
46	32	68	32
47	32	69	31
48	31.5	70	31.5
49	33	71	32
50	32	72	31.5
51	32.5	73	32
52	33	74	31
53	31.5	75	31.5
54	32	76	32
55	32	77	32.5
56	32	78	31.5
57	32	79	32
58	32	80	32.5
59	32.5	81	31.5
60	32	82	31.5
61	32	83	32
62	32	84	33
63	32	85	32
64	31.5	86	32.5
65	33	87	32
66	33.5	88	31.5

Table IV (cont'd.).

No. of bee.	Body temperature in degrees C.
89	32
90	32.5
91	31
92	31.5
93	32
94	32
95	32
96	31.5
97	32
98	31.5
99	32
100	34

Average body temperature 32° C.

Table V.

Air temperature 35° C.

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
1	35.5	23	35.5
2	35	24	34.5
3	35.5	25	35
4	35	26	35
5	35.5	27	35
6	35.5	28	35.5
7	36.5	29	35
8	35	30	35
9	35	31	35
10	35	32	35
11	37	33	35
12	35	34	36
13	35	35	35.5
14	35	36	35
15	35	37	35.5
16	35	38	35
17	35	39	35
18	35	40	35
19	34.5	41	35
20	35	42	35
21	35	43	35.5
22	35.5	44	35

Table V (cont'd.)

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
45	35	67	35.5
46	35.5	68	35
47	35	69	35
48	35	70	35
49	35	71	35.5
50	35	72	35
51	35	73	35
52	35.5	74	35
53	35	75	35
54	35	76	35
55	35.5	77	35
56	35	78	35
57	35	79	36
58	34.5	80	35
59	34.5	81	35
60	35	82	35
61	35	83	35
62	35.5	84	35
63	35	85	34.5
64	35	86	35
65	35	87	35
66	35	88	35

Table V (cont'd.)

No. of bee.	Body temperature in degrees C.
89	35
90	35
91	35
92	35
93	35.5
94	35
95	35
96	35
97	35.5
98	35
99	35
100	34.5

Average body temperature 35.1° C.

Table VI.

Air temperature 39.5° C.

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
1	39	23	39.5
2	39	24	40.5
3	39	25	39.5
4	39	26	38
5	38.5	27	39.5
6	39	28	40
7	39.5	29	39.5
8	40	30	40
9	39.5	31	40
10	39.5	32	42
11	40	33	39.5
12	40	34	40
13	39.5	35	39.5
14	38	36	39.5
15	39	37	39.5
16	39	38	40
17	39	39	39.5
18	39	40	39
19	39	41	39.5
20	39	42	39
21	39	43	39.5
22	39	44	39.5

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Table VI (cont'd.).

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
45	39.5	67	39.5
46	39.5	68	39
47	39.5	69	39.5
48	38	70	39.5
49	39.5	71	38.5
50	39.5	72	39.5
51	39.5	73	39.5
52	40	74	40
53	39.5	75	40
54	39.5	76	40
55	40.5	77	39
56	39.5	78	40
57	40.5	79	40.5
58	38	80	39.5
59	39.5	81	40
60	39.5	82	39.5
61	39.5	83	39.5
62	40	84	39
63	40	85	40
64	39.5	86	39.5
65	40.5	87	40
66	39	88	39.5

10-20 5M

Table VI (cont'd.).

No. of bee.	Body temperature in degrees C.
89	39.5
90	38.5
91	39.5
92	39.5
93	39.5
94	39.5
95	39.5
96	40
97	39.5
98	39
99	39.5
100	39.5

Average body temperature 39.5° C.

Table VII.

Air temperature 43.5° C.

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
1	42.5	23	43
2	42.5	24	43
3	43	25	43
4	43	26	44
5	43	27	44.5
6	43	28	43.5
7	43	29	43.5
8	43	30	43.5
9	43	31	43.5
10	42	32	43.5
11	43	33	44
12	43	34	43
13	43	35	44
14	42.5	36	44
15	43	37	44
16	42.5	38	44
17	43	39	44
18	43	40	44
19	43	41	44
20	43	42	44
21	43	43	44
22	43	44	44

Table VII (cont'd.).

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
45	43.5	67	44
46	44.5	68	44.5
47	44	69	43.5
48	44	70	44
49	44	71	44
50	44	72	44.5
51	43.5	73	43.5
52	44	74	44
53	44.5	75	44
54	43.5	76	44.5
55	44	77	44
56	44	78	43.5
57	43.5	79	44
58	43.5	80	43.5
59	44	81	44
60	44	82	43.5
61	44.5	83	44
62	43.5	84	44
63	44	85	44.5
64	43	86	44
65	44	87	44
66	44	88	44

10-20 5M

Table VII (cont'd.).

No. of bee.	Body temperature in degrees C.
89	44
90	43.5
91	44
92	44
93	44
94	43.5
95	44
96	44
97	44
98	44
99	44
100	44

Average body temperature 43.6° C.

Table VIII.

Air temperature 52° C.

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
1	46	23	47
2	47	24	46
3	47	25	46
4	45	26	46
5	48	27	46
6	46	28	46
7	46	29	46.5
8	46	30	45
9	46	31	46.5
10	46	32	47
11	46	33	46
12	46	34	46
13	46	35	45
14	45.5	36	46
15	46	37	45.5
16	46	38	46
17	45	39	46
18	46	40	45
19	46	41	46
20	45	42	45
21	46	43	46
22	46	44	46

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Table VIII (cont'd.)

No. of bee.	Body temperature in degrees. C.	No. of bee.	Body temperature in degrees C.
45	46	67	46
46	47	68	47
47	46	69	46
48	45	70	46
49	46	71	46
50	47	72	45
51	46	73	46
52	46	74	46
53	45	75	46
54	46	76	46.5
55	45	77	46
56	46	78	46
57	46	79	46
58	46	80	46
59	46	81	45
60	46	82	46.5
61	46	83	46
62	46	84	46
63	45	85	46
64	46.5	86	46
65	46	87	47
66	46	88	47

Table VIII (cont'd.)

No. of bee.	Body temperature in degrees C.
89	46
90	47
91	46
92	46
93	47
94	45.5
95	46
96	47
97	46.5
98	45.5
99	46
100	46

Average body temperature 46° C.

Table IX.

Air temperature 58° C.

No. of bee.	Body temperature in degrees C.
1	45.5
2	47.5
3	47
4	46
5	46
6	47
7	46
8	45.5
9	48
10	46
11	46

Average body temperature 46.4° C.

Table X.

Air temperature 52° C.

11:02 A. M. Bee placed in temperature box.

Time of piercing.	Body temperature in degrees C.	Remarks.
11:27	46	Slight movement of abdomen.
11:28	48	Considerable movement of abdomen.
11:29	48	Slight movement of abdomen.
11:30	48	No movement of abdomen.
11:31	48	No movement of abdomen.
11:32	48	No movement of abdomen.
11:33	48	No movement of abdomen.
11:40	52	

Table XI.

Check.

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
	24° C.*		30° C.*
1	29.5	1	32
2	27	2	32
3	28	3	32
4	28	4	31.5
5	27.5	5	31.5
6	29	6	32.5
7	28	7	32
8	28	8	31
9	27	9	32
10	28	10	32
Average	28° C.	Average	31.9° C.
	27° C.*		35° C.*
1	28.5	1	35
2	29	2	34.5
3	29	3	34
4	29.5	4	35
5	29.5	5	34
6	29.5	6	35
7	29	7	35
8	29.5	8	34
9	28	9	34
10	29	10	34.5
Average	29.1°C.	Average	34.5°C.

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Table XI (cont'd.)

No. of bee.	Body temperature in degrees C.	No. of bee.	Body temperature in degrees C.
	39° C.*		52° C.*
1	38.5	1	46.5
2	38	2	45.5
3	39	3	46
4	38.5	4	46.5
5	39	5	47
6	38.5	6	46
7	39.5	7	46
8	39	8	45.5
9	38	9	46
10	39	10	45.5
Average	38.7° C.	Average	46.1° C.

* Air temperature at which bees were pierced.

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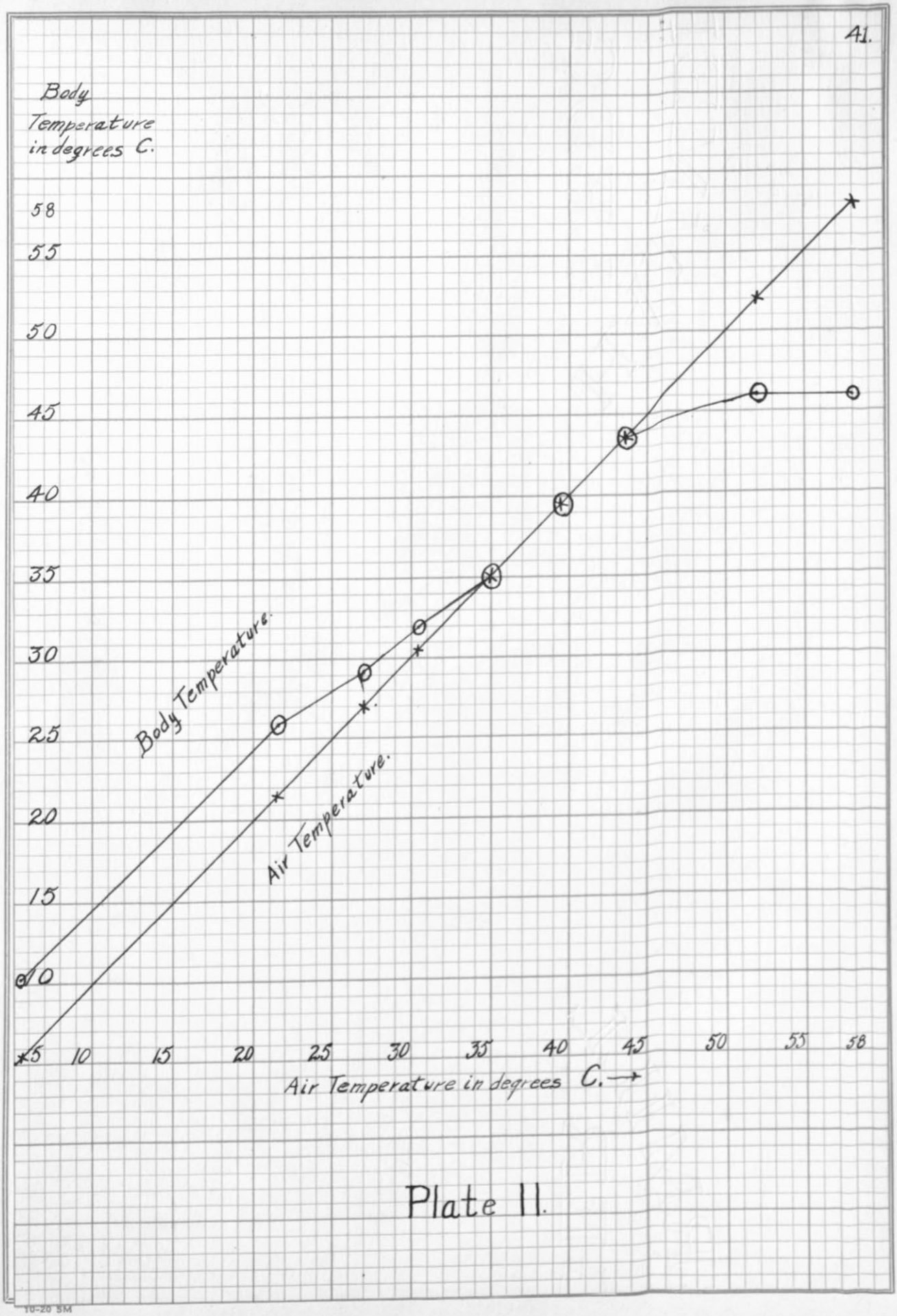

Plate 11.

In Tables I and II the difference between the average body temperature of the bees and that of the air was 4.6° and 4.4°C. respectively. A striking fact noted in the tables was the small range in differences in the readings at each temperature. This was especially noticeable at the higher temperature. In Table I there was a range of 5°C. in the readings for one hundred bees, while in Table II there was a range of 9°C. in the same number of readings. Table III showed a range of only 1.5°C. in fifty-four readings. In Tables IV, V, VII, VIII, and IX there was a range of 2.5°C. present in each table, while for Table VI there was a range of 4°C.

That the bees were capable of regulating their temperature for a short period of time was shown by the fact that when the bees were placed in the temperature box at 52° and 58°C. their body temperature did not correspond to that of the air, as it did from 35° to 44°C., but was lower. A few bees were tried at a low temperature -10° to -21°C. and it was noted that the temperature of the body fell with that of the environment. A bee was placed in a small vial which was placed in an ice bath. The bee was pierced with the thermocouple, and the reading was made by taking the difference between the warm junction in the body of the bee and the cold junction which was also inserted in the vial. The thermocouple was placed in the thorax and after the difference between the two junctions was taken the thermocouple was removed and re-inserted in about three minutes. In the case of one bee the couple was placed in the thorax and left there for twenty-five minutes. As the temperature was lowered the difference between the two junctions of the

thermocouple increased. The couple was then removed and immediately re-inserted and there was no difference between the two junctions of the couple. This can be explained by the fact that copper, being a good conductor of heat, conducts the heat downward to the body of the bee.

By handling the bees in individual cages, they were not excited before piercing. The space allotted to each bee was large enough to permit it some movement but not large enough for it to make use of its wings. Throughout the entire experiment only two bees, Numbers 62 and 71, Table I, were observed to be fanning. They were immediately pierced and found to give a reading 8°C. above that of the room, while those not fanning had a temperature about 4.6°C. above the air temperature.

When bees were exposed to the temperature of 5.5°C. they were taken into the room in groups of fifteen. A period of three minutes elapsed before the piercing of each successive bee to permit the thermocouple to return to room temperature. After the piercing of about the sixth bee, the remainder of them became motionless but were easily revived by holding them in one's hand for a few minutes.

After a group of ten bees were kept in the room for a period of two hours, they were pierced and they gave an average temperature of 2°C. above the room temperature. After the bees were kept at this low temperature for forty-eight hours they were dead and recorded the same temperature as that of the surrounding air. The bees may have died from starvation or from cold.

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When readings were taken at "room temperature" the work was done in the laboratory and the temperature varied from 19.5° to 24°C. with an average of 21.5°C. The bees were brought into the laboratory in groups of ten. At all other temperatures, with the exceptions of 52° and 58°C., the bees were used in groups of twenty-five.

As the air temperature was increased the difference between the body temperature of the bee and the temperature of the air decreased until at 35°C., or brood rearing temperature, the two corresponded. As the air temperature went up from 35° to 44°C. the temperature of the bee and that of the surrounding air were the same, as shown in Tables V, VI, and VII.

When readings were taken at 52° and 58°C. the time factor entered, as the bees were at the point of their fatal temperature (about 46-48°C.). In Table X the bee was placed in the temperature box for twenty-five minutes before piercing. The thermocouple was placed in the thorax and kept there for seven minutes, recording readings every minute, during which time all movement ceased. Seven minutes later the couple was again inserted in the thorax and the body temperature of the bee was identical with that of the surrounding air. For the one hundred bees used at 52°C. there was an average body temperature of 46°C. If left at this temperature for thirty minutes the bees died which indicated that the fatal temperature was around 46° to 48°C.

Conclusions.

From the above results the following conclusions were made:

Between 5.5°C. and 24°C. the difference between the body temperature and that of the surrounding air was about 4.5°C.

As the temperature went up from 24° to 35°C. the difference between the temperature of the body and that of the air decreased.

From 35° to 44°C. the temperature of the bee's body and that of the air were identical.

At 52°C. or above the temperature of the bee's body was lower than that of the air if not exposed to the high temperature for a long period of time.

The fatal temperature of bees lies at about 46° to 48°C.

Bees are not wholly subject to the temperature of their environment, but are capable, within certain limits, of regulating their body temperature.

The ability of a colony to regulate its temperature is undoubtedly due, to a certain extent at least, to the ability of the individual to regulate its body temperature.

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