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The Specific Heat of Insects[1)]

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(With 1 Text-figure)

In order to learn the relationship between the unfreezable water (bound water) and the cold hardiness in some insects, the amount of ice formed in the body at subzero-temperatures has already been measured by various methods[2)]. In the calorimetric method[3)], however, the value of the specific heat of the body is necessary for computing the amount of ice. For some years, the author has studied on the freezing curve of the slug moth, *Cnidocampa* (*Monema*) *flavescens*[4)]. In the course of the studies, it has been necessary to ascertain the amount of ice formed in the body under various freezing conditions, in order to analyse the freezing curve precisely. To achieve this purpose, the measurement of the specific heat of the slug moth and some other insects respectively was made first with the results reported in this paper.

The insects employed were *Oedaleus infernalis*, *Atractomorpha bedeli*, *Gryllulus mitratus* and *Cnidocampa flavescens*. A water calorimeter[5)] was used in determining the specific heat of the insects. The main part of the calorimeter consists of four copper vessels inserted inside of each other according to size, and of a water jacket enclosing the four vessels. These copper vessels are fixed with bakelite rings and cork discs so as not to come in contact with each other and are plated with nickel in order to reduce the radiation of heat from or to the calorimeter vessel. The water jacket, through which tap water is circulated, serves to keep the temperature of the parts surrounding the calorimeter vessel practically constant. The innermost smallest vessel (2.6 cm. in diameter and 3.5 cm. in height) with a lid is used as the calorimeter vessel. In addition to these, the calorimeter is provided with a stirrer which is composed of a bakelite shaft and small copper screw and is driven by motor (1/30 HP) to make uniform the temperature of the

1) Contribution from the Biological Institute, Ibaraki University, No. 24.

2) Consult Scholander *et al.*; J. Cell. & Comp. Physiol. 42, Supplement, 1, 1953.

3) This method is based on the facts that the heat capacity of the frozen animal is less, owing to the difference in heat capacity of ice and that of water, than the unfrozen one, and that ice absorbs the latent heat on fusing to water.

4) For references, see Asahina, Aoki and Shinozaki : Bull. Ent. Res. 45, 1954.

5) This calorimeter was originally devised by Porf. Z. Yosida, Applied-Physics Section of the Institute of Low Temperature Science, Hokkaido University, Sapporo. The measurements in the present study were made with the calorimeter, which was modified to smaller size than the original.

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water in the calorimeter during the measurement. In measuring the specific heat, ca. 15 cc. of pure water was pippeted into the smallest vessel and the exact amount of water was evaluated by weighing.

The temperature was measured by a copper-constantan thermocouple (0.2 mm. in diameter); the deflection of the galvanometer by one degree C. corresponded with ca. 12 mm. of the scale. The error of temperature measurement, even if its maximum value was adopted, was within ± 1/10th degree C.

The water equivalent of the calorimeter was estimated by two methods. In one method, it was evaluated by multiplying the mass of the vessel including the lid and the screw by the specific heat of copper (9.19×10^{-2}cal./gm./deg.), assuming that the whole vessel is constituted only of copper. The other method consists in determining experimentally this value as follows: from the decrease of the temperature which occurred by introducing a piece of ice (0°C) into the calorimeter vessel, the water equivalent was estimated by the following equation. The ice, after the water had been wiped from the surface with filter paper or gauze, was instantly dropped into the vessel and after the measurement, its amount was determined from the increment of weight. The equation is

$$w = \frac{[79.60+t_2+\Delta(t_2)]W_i-[\Delta(t_1)-\Delta(t_2)]W}{t_1-t_2} - W$$

where: w = water equivalent of calorimeter

79.60 = heat of fusion of ice

t_1 and t_2 = initial and final temperatures in calorimeter vessel, respectively

W_i = mass of ice

W = mass of water

$\Delta(t_1)$ and $\Delta(t_2)$[1] = correction based on the change of specific heat of water with temperature.

The values of the water equivalent of the calorimeter obtained by the two methods are presented in Table 1. The two values agree with each other. In view of the fact that the material of the calorimeter vessel includes other metal in addition to copper, the measured value for water equivalent was preferred to the calculated value in the subsequent measurements. The measured value perhaps contains error resulting from uncertainty regarding the mass of the ice, because, in the process of dropping the ice into the calorimeter, a thin surface layer of the ice may be thawed. The value of the water equivalent of the calorimeter is so small in comparison with the mass of water (ca. 15 gm.) that the error in this value is negligible in the determination of specific heat. Using the measured value of

1) As shown by Yosida (1944), the value of $\int_{t_1}^{t_2} C_w\,dt$, where C_w represents the specific heat of water in certain temperature range, may be conveniently obtained as follows: if expression $\Delta(t)=\int_0^t C_w dt - t$ is used, the relation follows: $\int_{t_1}^{t_2} C_w\,dt=[t_2+\Delta(t_2)]-[t_1+\Delta(t_1)]$. See W.A. Roth (Zeitsch. f. phys. Chem., A, 183, 1938) for the values of $\Delta(t)$.

Table 1. Water equivalent of calorimeter

	water equivalent	No. of measurements
calculated value	0.85	
measured value	0.896± 0.177	12

the water equivalent, the heat of fusion of ice was estimated to be 76.1 and 79.4 cal./gm. The error in mean value is about 2%.

The specific heat of an insect was measured individually except in the case of small specimens. In the measurement, the weighed animal was loosely tied with a copper wire which served to sink the animal into the water and to restrain its movement. The animal was previously cooled to 0°C. in a small copper box embedded in ice for 25 to 30 minutes, before being placed in the calorimeter. After the measurement, the animal was dried in thermostat at 110°C. to determine the water content. The specific heat of the insect was computed from the change of temperature in the calorimeter caused by the introduction of the insect, using the following equation :

$$C = \frac{(W+w)\,(t_1-t_2)+W\,[\Delta\,(t_1)-\Delta\,(t_2)]-0.092\,mt_2}{Mt_2}$$

where : C = specific heat of the insect[1)]

0.092 = specific heat of copper

m = mass of copper wire

M = mass of insect.

One example of the measurements is shown in Figure 1. The final temperature t_2 must be corrected, as the final temperature does not show the correct value owing to the transfer of the heat by some gradient of temperature between the calorimeter vessel and the water jacket. This correction was always made for t_2. The results obtained by the foregoing method are summarized in Table 2.

The specific heats of some insects obtained in the present study agree fairly well with that of the codling moth larva, the value of which was determined by Siegler (1933 and 1946) to be 0.71 to 0.77 and was calculated by Ditman et al. (1942) to be ca. 0.80, from the specific heats respectively of the dry matter and water of insect.

As indicated in Table 2, it might be pointed out that the higher the water content of the insect is, the greater its specific heat becomes. The correlation coefficient between the two is 0.42 which is stochastically significant. The same opinion held by Rosenthal (1878) regarding this relationship was cited by Bělehrádek (1935).

1) Specific heat cf the insect obtained in this manner is the mean specific heat expressed by the relation

$$C = \int_0^{t_2} C'\,dt \Big/ t_2$$

where C′ is the specific heat of the insect in certain temperature range.

Table 2. Specific heat of some insects

Species	Stage	Sex	Sp. heat cal./gm./deg.	Water cont. (%)	No. measured
Oedaleus infernalis	Adult		0.76 ± 0.05	65.7	5
Atractomorpha bedeli	Adult	Male*	0.68	63.1	2
		Female	0.74 ± 0.02	65.9	5
Gryllulus mitratus	Adult	Male	0.74	68.4	1
		Female	0.74 ± 0.02	66.4	4
Cnidocampa flavescens	Full-grown larva		0.83 ± 0.01	80.5**	4
	Prepupa		0.72 ± 0.01	61.5	4

* This species presents sexual dimorphism and the male specimen is much smaller than the female. Therefore, the specific heat of male was determined in the group of 2 to 3 individuals.

** This value alone is taken from previous report (Aoki and Shinozaki, 1953).

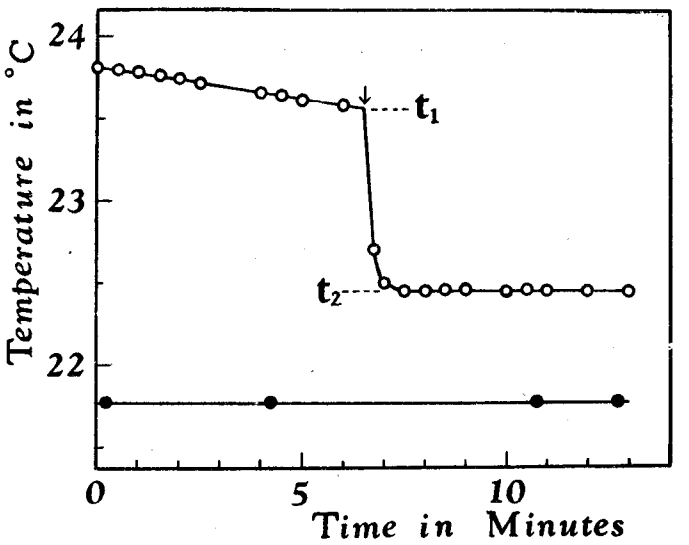

Fig. 1. Temperature-change in the calorimeter in determining the specific heat of *Gryllulus mitratus* (female, 1.042 gm). Open circles represent temperatures in the calorimeter vessel and solid circles those in the water jacket. Arrow shows the instant, at which the insect was dropped into the calorimeter. The specific heat estimated in this measurement is 0.73 cal./gm./deg.

As already mentioned, the specific heats estimated here are the mean values in the temperature range from 0°C. to the final temperature, t_2(20°-25°C.). Kanwisher (1955) states that the specific heats of tissue and shell, etc. in intertidal gastropods and bivalves

are not appreciably altered by temperature. Therefore, it might be supposed that the specific heat of insects is also practically constant independent of temperature; the precision of the instrument used in the present study is not sufficient to detect a little variation, if there is any, in specific heat.

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Summary

1. The specific heat of some insects was calorimetrically determined.

2. The results obtained are as follows : the specific heat is 0.76 cal./gm./deg. and water content 65.7% for the adult of *Oedaleus infernalis*; 0.68 and 63.1% respectively for the male, 0.74 and 65.9% respectively for the female of *Atractomorpha bedeli*; 0.74 and 68.4% for the male, 0.74 and 66.4% for the female of *Gryllulus mitratus*; and 0.83 and 80.5% for the full-grown larva, 0.72 and 61.5% respectively for the prepupa of *Cnidocampa flavescens*.

3. From the above data, it may be definitely stated that the specific heat of the insect becomes greater with the rise of water content.

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