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Physiology. — "*Some calorimetrical investigations relating to the manifestation and amount of imbibition heat in tissues*". By Dr. V. E. NIERSTRASZ. (Communicated by Prof. ZWAARDEMAKER).

(Communicated in the meeting of February 27, 1912).

Amongst the numerous physico-chemical processes which throw more light upon the nature of function, an important place has been occupied of late years by imbibition [1]).

We mean of course the real molecular swelling, mostly viewed as a diffusion phenomenon [2]), not the capillary or endosmotic imbibition. As a point of departure for some investigations in this direction we took imbibition-heat, other characteristics of the swelling viz. volume-contraction of the entire mass of substance + water [3]), and swelling pressure, being more remotely connected with the nature of imbibition.

Keeping in view the fact that most calorimetrical determinations take up much time, we did not take the ice-calorimeter, generally [4]) adopted for this purpose, but followed a method which, to a great extent, obviated this difficulty, and moreover, allowed of the determinations being made at the temperature of the room.

Our method was in principle a bolometrical one; the heat developed was measured by resistance-modifications in a thin copper-wire isolated with silk and wound bifilarly (thickness 0.1 millimetres), resistance 25 Ohms). We used two bolometers as much like each other as possible (b_1 and b_2 in the figure, length of tube 14 c.m., inner diameter 1,9 c.m., outer diameter 3 c.m.); the side was formed by a DEWAR's glass, which made the isolation as perfect as possible. These were taken up as branches in a system, based on the principle of WHEATSTONE's bridge, and had each as a counter-resistance

1) W. OSTWALD, Koll. Zustand der Stoffe, Oppenheimer's Hdb. d. Biochemie. Bd. I. p. 839.

L. MICHAELIS, Physik. Chemie der Kolloide in Handbuch Physik. Chemie und Medizin, Korányi und Richter. Bd. II. Leipzig 1908.

M. H. FISCHER, Das Oedeem. Dresden 1910.

H. FREUNDLICH, Kapillarchemie. Leipzig 1909.

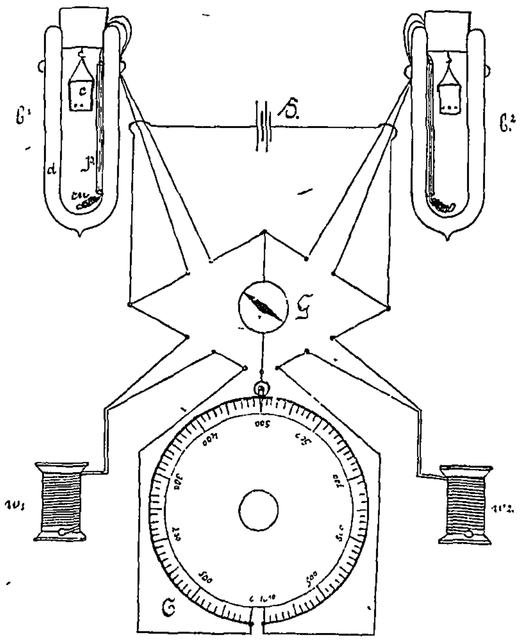
2) J. Reinke, Untersuchungen über die Quellung einiger vegetabilischer Substanzen. Botanische Abhandlungen. Bd IV. Heft 1.

3) The substance itself of course increases in volume.

4) O. KRUMMACHER, Ueber die Quellungswärme des Muskelfleisches. Zeitschrift für Biologie. Bd. 52 Heft 4 und 5.

v. D. HOEVE, Opzwelwarmte der lenszelfstandigheid. Ned. Tijdschrift v. Geneeskunde. 28 Oct. '11.

a thin copper wire wound on a bobbin (w_1 and w_2) and a thin niccoline wire, any part of which could be added to the resistance



by means of a movable post, enabling us to fix the resistance at the length required. These two counter-resistances could undergo with respect to each other some modification in size by the insertion of a round compensator *c* of Du Bois Reymond, which on being turned effected another division of the lengths of the two parts to be passed by the current ($S =$ key, $G =$ galvanometer).

The Dewar's glasses were placed in a cube shaped calorimeter (length of the ribs 42 cm.) consisting of two layers, an inner layer of cork (thickness 3.5 cm.) and an outer layer of wood. A cover of the same materials closed the whole. The Dewar's glasses, fixed in a wooden stand, had been placed in the middle of the calorimeter on a narrow horizontal plank, the round extremity of which pierced the calorimeter on one side, and was connected with a wooden handle, which rendered it possible to make the whole revolve round a horizontal axis. An advantage of this was, that whilst the calorimeter and the Dewar's glass were closed, it was possible to effect the contact between tissue and fluid in the manner to be described below.

On either side the counter-resistances had been fastened to the inside on a little plank. The round compensator stood apart, likewise in a secluded space. It was covered by a glass plate, provided with a little opening from which a magnifying glass projected, which allowed the divided scale to be read off accurately. The turning was effected by means of two cords, wound in different directions round the axis; these on being drawn rotated the divided scale in opposite directions. As these cords (like the current-wire) passed out through openings in the side, it was possible to effect the rotation with the box closed. In the same way the wire-connections of the calorimeter passed out.

All these were united, according to the above-mentioned plan, on a system of posts fastened on the outside (see fig.). It goes without saying that thorough isolation was necessary against the changes in the temperature (wadding, felt) for the counter-resistances inside, as well as for the connections outside.

The bolometer itself was composed as follows (see fig.). On the bottom of the DEWAR's glass (∂) were the clew-shaped [1]) copper wires, which were wound bifilarly. The two ends were led upward through a thin glass tube (*p*) (fastened to the side with sealing-wax) and were connected by means of a thicker copper-wire with the posts.

The DEWAR's glasses were closed by means of an india-rubber stopper, to the bottom of which a hook was attached on which the little pail (*e*) was hung, destined to contain the tissue to be experimented upon. Before the experiment began this had to remain of course above the level of the fluid in the tube (dimensions of the pail were: heighr 2.5 cm. outer diameter 1 cm.).

Thus it was possible, the bolometer being closed, to wait till the needle of the galvanometer was at rest, a state of perfect equilibrium having set in; then the handle was turned, which caused the pail to drop from the hook bringing it into contact with the fluid. Pail and bolometer-wire always came down immediately in the same position, side by side.

In order to determine the amounts of heat we did not make use of the deviations of the galvanometer needle, but of the extent to which the compensator had to be turned in order to keep the needle at zero. The divided scale of the compensator rendered it possible to read off this change. For shortness, sake we shall henceforward call the round compensator of DU BOIS REYMOND measuring-wire. It goes without saying that the relations between the volumes of heat developed, were different from those indicated by the measuring-wire (the measuring-wire forming only a small part of the counter-

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[1]) At first we used a copper-wire, wound spirally on a pin 5 cm. high, in the middle of which the tissue came down. Its sensibility was, however, 5 times smaller than if the clew form was adopted, so that the latter was always used.

resistances), and that every point had to be separately determined. More will be said about this later on.

Now we intended to collect by means of the imbibition heat some data relating to the imbibition of different tissues of different animals. For this purpose we chose the fresh-water mussel, the rabbit, the pigeon, the neat.

Anodonta fluviatilis has two adductors, the central yellow part of which has the function of a fast muscle, whilst the peripheric white part may be for a long time in a state of tonus [1]). The parts of these muscles also differ histologically.

Since according to ENGELMANN the contraction is attended by a water displacement in the muscular fibrils, it is conceivable that the colloid substances of the hypothetical inotagmas absorb this water. It might be supposed then that in such muscles more substances liable to swelling are found than in the peripheric parts of the muscle, which are in a state of autotonus.

We experimented upon chopped up tissue, which was then exposed for half an hour to a hot current of air (40° C.) and was further dried during two days in a vacuum-exsiccator at 40°.

We then obtained a fine powder of which we established the amount of water lost, by weighing it before and after it was dried. When it was left longer in the exsiccator, this loss increased at most with 1—2°/₀.

It is generally held that an arithmetrical decrease of water-percentage causes a geometrical increase of imbibition-heat. Here, however, the differences in water-percentage, during the various determinations of one tissue, were so small that they could not be recognized as influencing the results any more than the small temperature changes during the experiment (the extremes were 10 and 14° C.).

We subjoin the relative results of 10 series of experiments on anodonta-organs, both for the tissue-powder and calculated for the fresh tissue from these values, and the loss of water caused by exsiccation, which was known. To facilitate comparisons we fixed the value of the fast muscle at 100 whilst the other results were reduced in the same proportion. Our determinations were always made with doses of 50 milligrammes and we took the average scale-movement of the measuring-wire. In this way a slight mistake is made as these deviations are not quite proportional to the heat developed, but in the case of small differences this is not of much importance.

[1]) J. PARNAS, Energetik glatter Muskeln. Pflüger's Archiv., Bd. 134.

The time taken up by the experiment was 3, at most 5 minutes, after that no more heat was taken up. We always worked with equal volumes of fluid, the other conditions being likewise always the same, so that, to compare the results, the capacity for heat of the apparatus need not be taken into account. We may safely assume that with heat-quantities such as these the distribution of heat over copper-wire, fluid and glass is always effected in the same way, when the experiments are carried out in this manner.

Fresh water mussel.

Relative and average values of the imbibition-heat of:

	yellow (fast) muscle	white (autotonous) muscle	lever	organ of Bojanus	mantle	corpus
a. tissue-powder	100	80.9	71.7	65.1	36.5	38.3
b. calculated for fresh tissue .	100	80.3	40.2	51.1	41.9	47.8
c. loss of water by exsiccation	84 2 %	83.5 %	90.6 %	88 %	80.6 %	78.9 %

We observe indeed distinct differences and that most between the muscle-tissue on the one hand and the other tissues on the other.

These differences are still more manifest in the fresh tissue.

The difference between the two kinds of muscles exists so far that the fast muscle swells most, but it is too slight to admit of general conclusions being drawn from it as to the nature of the functions.

From the results obtained with dry powder it might further be inferred that the secretion or excretion organs such as liver and organ of Bojanus contain these substances in a higher degree than the other, more indifferent, organs. Possibly this may be connected with the secretory function of these organs; it may be conceived that the process of imbibition is of importance as a preparation to further stages.

Under exactly the same conditions the following series of experiments was carried out with the organs of the rabbit.

The loss of water caused by the exsiccatory process varied in different organs from 77 to 83 %. We subjoin again some average relative results.. On every organ at least 10 determinations were made (10—18).

Rabbit.

Relative and average values of the imbibition-heat of:

	white muscle	red muscle	kidney	brain	liver
a. tissue powder.	100	104.7	126.1	91.2	94.1
b. calculated for fresh tissue . .	100	114.4	114.4	78.3	93
c. average loss of water by exsiccation	78.6°/₀	76,6°/₀	80.6°/₀	81.7°/₀	78.9°/₀

Here we find the differences between the tissues not so great as with anodonta; moreover we find, besides the muscles, especially the red one, the swelling of the kidneys at the head of the list; for the dry tissue it is even greatest. The swelling of the liver too, is above that of the central nerve-system. As in the case of anodonta we see here too that the secretion (excretion) organs have a relatively great imbibition-heat.

In order to be able to put absolute values by the side of these relative ones, various methods of measurement were adopted. The most satisfactory was that effected by JOULE's heat.

For the current-circuit to be constructed the various wire-connections were chosen in such a manner that their resistance could be neglected; besides, however, a thin isolated niccoline-wire of a given resistance was also inserted into the circuit, this wire, wound in a spiral of no great height was put on the bottom of the pail.

Thus the spiral had exactly the same position as the tissue-powder in the experiment.

This resistance had been taken up into the circuit by being soldered to two thicker varnished wires, which issued from between stopper and glass side, and which were connected with the current-circuit by means of posts.

We had to experiment of course with such currents that their heat-development caused deviations on the measuring wire of about the same magnitude as those effected by the tissue-imbibition.

From the preceding determinations with glass-powder we knew approximately how much heat was set free at a given deviation, and could therefore establish, starting from the physical formula: heat $= \frac{1}{4.2} i^2 \Omega t$, the quantities we had to deal with. The duration of the current was fixed at 3 minutes, that is the time during which heat is still absorbed. The resistance of the niccoline-wire was 21 Ohms at a thickness of 0.15 millimetres and a length of 40 centimetres.

At a temperature of 14° C.[1]) we now got at a current-strength (i) of 30, 40 and 50 milliampères (m.a.) deviations on the measuring-wire of 46, 66 and 105 division-marks respectively. These deviations, therefore, increased proportionately more than the strength of the current and less than its square, which might indeed be expected.

Of the deviations between two determined points which were pretty close to each other, we found the absolute value by linear interpolation. The trifling mistake thus made, could not be of much importance.

We saw that for the white muscle tissue of the rabbit the average deviation was 68.5, that is about as great as the one obtained at a current of 40 m.a. at the absolute determination (66). As, however dissolved and jelly-like substances gather on the clew of the bolometer, causing the deviations on this side to be 2 or 3 times smaller than on the other[2]) the determination of the absolute value[3]) must always take place immediately before or immediately after a series of experiments.

In the following series of experiments made with the muscle-tissue of the pigeon and neat, we made, therefore, an absolute determination in connection with every series and under the same conditions. Of the pigeon we used three kinds of muscles viz. the smooth tonic stomach muscle, the heart muscle, and a striated thoracal muscle and compared these values, both as regards their relative and their absolute imbibition-heat. In these experiments we used doses of 100

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1) The current being the same the deviations increased somewhat at the ganging when the temperature fell.

2) When it is thoroughly rinsed and left in water for one day, the old sensibility of the wire is restored, as compared with the other side. In the long run, however, some decrease seems to take place on both sides possibly by defects of the isolation manifesting themselves.

3) This method we also applied in determining the effect of the volume of the fluid in the DEWAR's glass It was found to be very small.

We mostly put on both sides 10 cm³. into the tube, but double this volume and a current of 40 ampères had no effect on the deviations. Also when we took 4 times this volume (5 and 20 cm³.) and a current of 100 m.a. the effect remained doubtful, at any rate but slight (a difference of only 4 division-marks). Hence the capacity for heat of that part of the fluid which was heated is at any rate but small, and moreover always the same; as we may further assume that the relative distribution of the heat over copper-wire, water and glass is always the same for the quantities of heat under consideration, it is unnecessary to pay any further attention to the capacity for heat of glass and water.

milligrammes; in the case of pigeon I we made for every muscle 10 determinations, for pigeon II 5:

Pigeon I

	stomach muscle	heart muscle	thoracal muscle
a. average relative values.	100	90.2	89.9
b. absolute values per 1 gramme of tissue-powder	8.1	7.1	7.0 gramme-calories

It follows from the above figures that the tonic smooth stomach muscle has a somewhat greater imbibition-heat than the others, whilst there is no marked difference between the imbibition heat of heart-muscle and thoracal muscle.

Pigeon II.

	stomach muscle	heart muscle	thoracal muscle
a. average relative values	100	86.9	97.8
b. absolute values. .	10.2	8.5	9.9 gramme-calories

Here too the stomach muscle has the greatest imbibition-heat though the difference with the other values is smaller. The thoracal muscle has a somewhat greater imbibition-heat than the heart-muscle.

The average absolute values of the two series are therefore 9.15, 7.8 and 8.5 gramme calories.

Finally we shall compare these absolute values with those which were obtained by KRUMMACHER [1]) by means of BUNSEN's ice-calorimeter as modified by SCHULTEN and WARTHA, so that an opinion can be formed about the two methods. KRUMMACHER determined the imbibition-heat of the musculus glutaeus max. of a newly killed neat (killed one hour before); we did the same and proceeded as before.

As an average of 10 determinations with 100 milligrammes of tissue-powder we found per gramme of muscle-tissue an imbibition-heat of 11.6 gramme-calories.

KRUMMACHER found for dried muscle tissue, which, for the rest had been left unchanged, 8.3 gramme-calories, for flesh which had been extracted first 13.1 gramme-calories.

1) O. KRUMMACHER. Ueber die Quellungswärme des Muskelfleisches, Zeitschrift für Biologie, Bd. 52, Heft 4 und 5.

Our values are between these; somewhat greater, however, than his for flesh which had only been dried. Our method is superior to his in the following respects:

1. the imbibition takes place at a more physiological temperature.

2. the determination takes much less time; 4 determinations can be made in one hour.

Only further researches can bring to light the best method of investigation; for the present it seems to me that the advantages mentioned are of some importance.

The great amount of imbibition-heat developed even by inconsiderable volumes of tissue, is at all events remarkable.

Conclusions.

1. In a dried state the organs of anodonta as well as those of warmblooded animals are found to be liable to imbibition, which imbibition is attended by a considerable development of heat.

2. Generally speaking the muscle-tissue develops the greatest heat; then follow kidney and liver.

3. Between muscles contracting rapidly and those contracting more tonically (white and yellow adductors of anodonta, heart- and stomach-muscle of pigeon) the differences in imbibition-heat are too slight to be of much value for contraction theories. At any rate it is not found that muscles with rapid contraction always develop the greatest heat.

4. The amount of imbibition-heat is for muscle-tissue of the pigeon on an average 8.5 for that of the neat 11.6 gramme-calories.

5. Advantages of the bolometrical method are a more rapid determination, and imbibition at a more physiological temperature.

6. The sensibility of the method is very great, one division-mark on the measuring wire denoting on an average 1 or 2 hundredths of a gramme-calorie.

Physiology. — *"On the ciliary movement in the gills of the mussel"*. By Dr. F. J. J. Buytendijk. (Communicated by Prof. Hamburger).

(Communicated in the meeting of February 24, 1912).

Since the time when Valentin [1]) enumerated four chief forms of ciliary movement viz. the motus uncinatus, vacillans, undulatus and infundibuliformis, deviating forms of motion have been described by other investigators. Although even the untrained observer can, upon the whole, recognize these forms of ciliary movement in various

[1]) Valentin. Flimmerbeweging In Wagners Handbuch der Physol. Bd. I p. 484—516.