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ON THE LIMITS OF TEMPERATURE COMPATIBLE WITH THE CONTINUATION OF LIFE, ESPECIALLY AS AFFECTING COLD-BLOODED ANIMALS

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"On the Limits of Temperature Compatible with the Continuation of Life especially as affecting Cold-Blooded Animals:"

I: INTRODUCTION:

One only needs to take up in his hand a frog, fish, toad, or snake and then handle such an animal as a rat, dog, or bird to discover where the terms "warm-blooded" and "cold-blooded" arose. Hunter (1) long ago pointed out that by "warm-blooded" animal was meant one that maintained a fairly constant temperature in all surroundings, while by "cold-blooded" animal was understood one whose temperature varied with that of its surroundings. Donders and Bergmann (1) have discussed the terms very fully also and pointed out their inexactness. The latter suggested the substitution of "poikilothermic" and "homoiothermic" animals for the old names "cold-blooded" and "warm-blooded" animals. The great difficulty arising from the use of the old terms lies in the fact that there is no sharp line of demarcation between the two great classes. A so-called cold-blooded animal may, in a tropical atmosphere, have a temperature quite as high as, or even higher than, a warm-blooded animal at a certain stage or under certain conditions. Then, too, we must bear in mind that the higher animals pass through a stage where they exhibit the so-called cold-blooded characteristic of a variable temperature. New-born pups have been subjected to a low temperature and by this means had their own temperature lowered to 17° or 18° C., and though kept at this low temperature for a considerable time, they have subsequently recovered on applying artificial

warmth.

Again, we must not forget the well-known phenomenon of hibernation. This is a seasonal torpor into which certain animals such as marmot, sisel, bat, bear, hedgehog, and dormouse sink and remain for considerable periods. The body functions become enormously lowered. No food or very little is taken during the period. Breathing is greatly reduced, from eighty or one hundred respirations per minute in the dormouse to sixteen or twenty. The heart rate is correspondingly slackened and the blood pressure low. The intake of oxygen and the output of carbon dioxide are reduced to a minimum. In this peculiar state the temperature falls and varies with that of the surroundings in the characteristic cold-blooded fashion. The internal temperature of a hibernating mammal has been reduced to 2° or 3° C., and the animal has subsequently recovered without showing any ill effect. The same reduction of temperature when the animal was not hibernating would be inevitably fatal. Hence we see that it is necessary not to insist too strongly on the distinction between "warm-blooded" and "cold-blooded" animals.

The frog may be taken as typical of what is meant by a cold-blooded animal. The temperature of this creature is usually very nearly that of its surroundings and varies as these do. But variations in temperature do not seem to affect the normal frog seriously provided they be not too great. This animal is remarkably well adapted for experimental purposes on account of the fact that after the death of the creature as a whole, the various tissues live for several hours and nerve and muscle may be readily dissected out and used to demonstrate

the action of living muscle and nerve within the body. When we remember also the ease with which a supply of frogs may be obtained and cared for it seems natural that many generalisations applying to cold-blooded animals should be based on experiments on amphibians. Unless otherwise specified the experiments recorded in this paper were performed on Rana pipiens.

People of an inquiring turn of mind must often have wondered just what are the limits of temperature that living organisms can survive. Plants (which are poikilothermic organisms) can survive a very wide range of temperature. On one hand there are certain plants which flourish in hot springs and on the other plants which are not apparently injured by subjection to the temperature of liquid air. In the animal world the variations are probably not nearly so great. In the case of vertebrates the range does not amount to more than 30° or 40° C, at most. It would be interesting to know with a reasonable amount of accuracy the limits of temperature (taken internally) which various classes of animals can survive. A certain amount of experimental work has been done on this subject but our knowledge is as yet very incomplete. The present paper is to be a summary of available evidence on the temperature limits of cold-blooded animals together with a report of a series of experiments which I have performed in an endeavor to widen the extent of our knowledge on the matter.

The early temperature work was not very accurate. Lord Lister stated that if one holds a frog in his hand for a quarter of an hour it will be found to kill the animal. It is true that the creature

has every appearance of death after this treatment, but if it be placed in a small amount of water at 10° or 12° C., it will be found to recover in a few minutes. Half an hour in the hand will not kill the animal or even seriously injure it as I have found when working with R. pipiens. Belaroche [1] stated that a frog can survive two hours exposure to temperature of 45° to 55° C., which is rapidly fatal to a rabbit, bird, or cat. I have shown conclusively that exposure to a temperature of 40° C. for a period of one hour or less will produce rigor mortis in the muscular tissue of the frog and from this there can be no recovery. On the other hand we have numerous references to the temperature limits of various animals in the fairly large volume of literature from the pens of naturalists and zoologists, who have not, as a class, a very good reputation for accuracy of observation.

II: LOW TEMPERATURE WORK:

It is a matter of common knowledge that in early spring, very soon after the first thaw, frogs appear, and it must be a matter of no little wonder where the winter was spent. We hear repeated tales of frogs dug up from the ground in the hard frozen condition, the inference being that their temperature approximates that of their surroundings which may be - 20° or - 30° C., and yet these same frogs recovering on being slowly warmed to + 10° or + 15° C. Fishermen tell similar tales of fish caught and thrown out on the land in cold weather. These may be frozen stiff and yet when thrown back into the water will swim away as soon as they thaw. It is stated on good

authority by competent observers(2) that frogs actually spend the winter in or about springs, the waters of which do not sink below 0^{o}C. While this is undoubtedly part of the truth we have still to find out where and under what conditions frogs winter in localities where there are no springs and where most of the ponds apparently freeze to the bottom during the early part of the winter.

The more extreme statements as to the degree of cold that poikilothermic animals can survive would seem at first sight to be amply substantiated by the evidence we obtain from the literature on the subject. Pembrey (1) has summed up the available evidence as follows:

"The limits of extreme cold are generally reached when the water in which the animals live, or the lymph of their tissues is frozen. Fishes live in salt water when the temperature is below zero, but usually die when the water is frozen.

"Boyle exposed lampreys in a vessel of water to an exceedingly sharp frost, and found next day that one lamprey was frozen to the ice; when the ice was partly broken and partly thawed the animal was at first motionless, but in a few minutes recovered, and dragged after it a large mass of the ice in which its tail was fixed. Similar

experiments were made with similar results upon gudgeons and frogs. Hunter found by experiment that the internal temperature of a frog and an eel could be reduced to -0.6°, and that, although the animals appeared to be dead, they revived when the temperature rose. Regnard found that carp will live in water containing 2½ per cent of magnesium sulphate, even when the temperature is a degree or two below zero; at -2° the fish appear to be asleep, and at -3° their vitality is so greatly reduced that they seem to be dead, but revive when the water is gradually warmed. Pictet exhibited at one of his lectures frozen goldfish, pike, and frogs, and at the next lecture the same animals alive and well after gradualy thawing. According to this observer fishes can be rapidly frozen so hard that they can be snapped in two, and yet other fishes frozen equally hard recover when slowly thawed. It has been observed by Marcet that goldfish completely embedded in the ice show no signs of life on thawing, but one fish, which was partly encased in ice and was surrounded by a little water, appeared lifeless, but recovered perfectly in a short time. Observations and experiments made by Garnard and Caverett show that toads and fishes may be frozen perfectly stiff and yet survive when gradually thawed; according to the former observer the freezing must be gradual, otherwise the animals are killed. During Franklin's explorations in the Arctic regions it was observed that fish frozen completely hard recovered when they were thawed; a carp, which had been frozen for thirty-six hours, was able when it had been thawed to leap about with much vigour."

And again (p. 623) "The eggs of silk-worms and of