TEMPERATURE CHARACTERISTIC FOR HEART BEAT FREQUENCY IN LIMAX.

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In order to obtain information as to the types of critical thermal increments for heart beat frequency in a variety of animals, and thus, it is to be expected, some knowledge of the kinds of controlling reactions, it was found desirable to reinvestigate certain more or less typical forms. The present note contains data upon the relation between temperature and frequency of cardiac pulsations in the slug Limax maximus.

The animals were obtained from a greenhouse, since at this season (March) they are inactive out-of-doors. Some days before the observations were made the anterior portion of the mantle was cut away. Each individual was studied by placing it about midway in a glass tube of just sufficient diameter to accommodate the slug. This tube (2 feet long) was surrounded by a much larger tube through which water at the desired temperature was passed. The temperature of the animal's surroundings could then be adequately controlled when the outer tube was then wrapped with cotton, except in the immediate vicinity of the slug. A sensitive, calibrated thermometer was adjusted in the smaller tube, with its bulb very close to the head of the slug. Light from a stereopticon lamp, passing first through heat filters and a diaphragm, was sufficiently intense to make visible the pulsations of auricle and ventricle. This illumination had itself no systematic effect on the heart beat. The removal of the anterior portion of the pigmented mantle increased visibility. For each observation the time for ten beats was measured. Precautions were taken to reduce errors from faulty thermal adaptation. It was not found necessary to arrange for a constantly renewed supply of air within the tube.

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Results with several individuals are given in Fig. 1. The logarithm of the frequency of heart beats is inversely proportional to the absolute temperature. The type of variation and the consistency in the comparative records of different specimens are similar to those encountered in cases previously studied (Crozier, 1924–25; Crozier and Federighi, 1924–25, a and c; Crozier and Stier, 1924–25). The critical increment (temperature characteristic) derived from Fig. 1 is \( \mu = 16,300 \pm 200 \text{ cal.} \)

![Graph](image)

**Fig. 1.** The frequency of the heart beat in *Limax maximus* as function of temperature; three individuals (different symbols). The points are in some instances single observations, but in many cases represent two or more coincident readings. The linear relationship satisfies the equation \( \ln \frac{K_2}{K_1} = \frac{\mu}{2} \left( \frac{1}{T_1} - \frac{1}{T_2} \right) \), where \( K_2 \) and \( K_1 \) are the frequencies at the respective absolute temperatures.

This value of the temperature characteristic of the neurogenic heart beat is of interest because it agrees closely with that derived from the consideration of certain somatic movements of *Limax* (Crozier and Federighi, 1924–25, b). The observations given in Fig. 1 refer to the heart beats of animals in a state of quiescence. If, however, the slug be moving—turning slowly, or creeping,—the frequency of the beats is immediately accelerated to an extent depending largely upon the vigor of the movements. So far as can be judged, the critical increment remains the same, but it is very difficult to secure sufficient observations under strictly comparable degrees of muscular
activity. A certain amount of the variation evident in Fig. 1 may be traceable to slight movements of the tentacles and mouth; one individual (No. 3), the most variable, was more restless than the others.

The temperature characteristic obtained with *Limax* may be compared with that calculated from published observations upon the heart beat in certain other molluscs.

Some interesting although not very numerous observations by Lang (1910) upon the heart beat of *Helix* at different seasons yield

![Graph showing frequency of heart beat in *Anodonta*](image)

**Fig. 2.** Frequency of the heart beat in *Anodonta*; data from Koch (1916-17). Between 8° and 26° a satisfactory fit is obtained with $\mu = 11,200$. Two series of observations are adjusted for comparison by dividing the frequencies in one set (white circles) by 2.38.

increments 7,900 (June), 11,300 (January), and 16,000 (February, March). This type of finding is suggestive because temperature characteristics of these particular magnitudes are associated with respiratory phenomena in a great variety of instances (Crozier, 1924-25; Crozier and Stier, 1924-25). It may be suggested that the mechanism determining heart frequency is different at different seasons, in *Helix*. The fact that incomplete experiments of our own with *Limax* in December gave $\mu = 7,900 \pm$ is confirmatory. Snyder (1906-07) gives data upon the heart beat of *Phyllirrhoe*, at four temperatures; from these $\mu = \text{about 10,700}$. Bachrach and Cardot
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(1923) measured the heart beat frequency in embryos of Arion; the mean frequencies at three intermediate temperatures yield $\mu = 12,700$. A few observations by Crozier and Arey (1919) on the heart of Chromodoris give $\mu = 12,300$. In these and in some other instances it is uncertain to what extent the magnitude of the deduced increment may be influenced by movements of the animals, or by the existence of undetected changes in $\mu$ on either side of some critical temperature. Koch's (1916–17) data for heart beat in Anodonta (Fig. 2) yield over the major portion of the temperature range the increment 11,200 cal. These facts tend to suggest that the reactions which in one or another case control the frequency of the heart beat of molluscs are those involved in a general system of processes constantly represented in living matter.

SUMMARY.

The temperature characteristic for the frequency of the heart beat in quiescent Limax maximus is $\mu = 16,300$ calories. This value agrees well with that obtained for certain neurogenic activities of the parietal musculature of this gastropod.

CITATIONS.

Lang, A., 1910, Festschrift zum 60. Geburtstag R. Hertwigs, iii.