ing somewhat fugitive developed colors, a series of brilliant azo dyes very fast to light.

Although the work mentioned in this paper deals with only a small part of the subject the evidence which has been secured indicates that the idea of molecular compound formation should be thoroughly tested. Since the organic chemist specializes in problems connected with molecular structure and the residual affinity of atoms or groups he may find this theory useful in the choice of negative catalysts for many purposes.

ON THE MEASUREMENT OF CRITICAL THERMAL INCREMENT FOR BIOLOGICAL PROCESSES

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The attempt to classify biological activities upon the basis of their velocities as affected by temperature[1] involves for a number of cases the adjustment of curves to data inevitably subject to several sources of variation. One of these arises from the fact that the measurements may be secured with different individuals at each of several temperatures. The latitude of variation in series of data obtained in this way may be large, and unless great numbers of observations are available interpretation may be difficult.[2] Indication already obtained as to the theoretical significance of the exact quantitative relationship between velocity of a vital process and temperature make it desirable to demonstrate the limits of variation in material which is as nearly as possible biologically homogeneous.

An illustration is provided by the frequency of the heart-beat in the silkworm. Larvae were bred from eggs given by Dr. R. W. Glaser. The caterpillars used came from eggs laid by one female; this fact, coupled with the highly inbred character of these animals, insures exceptional genetic uniformity. The heart-beat was counted for each of a number of individuals of the same age, reared throughout under identical conditions.[3] The details of these experiments well be described in another place. It is sufficient here to state that a larva when under observation was motionless and quietly feeding on a mulberry leaf, in a closed glass chamber immersed in water. The temperature was obtained with a thermometer reading to 0.01°C. We shall deal merely with the temperature affect above 15°C. Below this temperature, complications ensue and there occur changesw hich are only slowly reversible. It is significant that 15° is in this instance as

in so many others, [1,4] a "critical temperature" for organic phenomena; not only is the heart beat abruptly affected in a special manner by exposure to temperatures even slightly below 15°, but the larva promptly ceases to feed.

Observations made upon several individuals are plotted in Figure 1. The control of heart-beat frequently by temperature is adequately expressed in the equation

$$\frac{Frequency_2}{Frequency_1} = e^{\frac{\mu}{2}\left(\frac{1}{T}-\frac{1}{T_1}\right)}$$

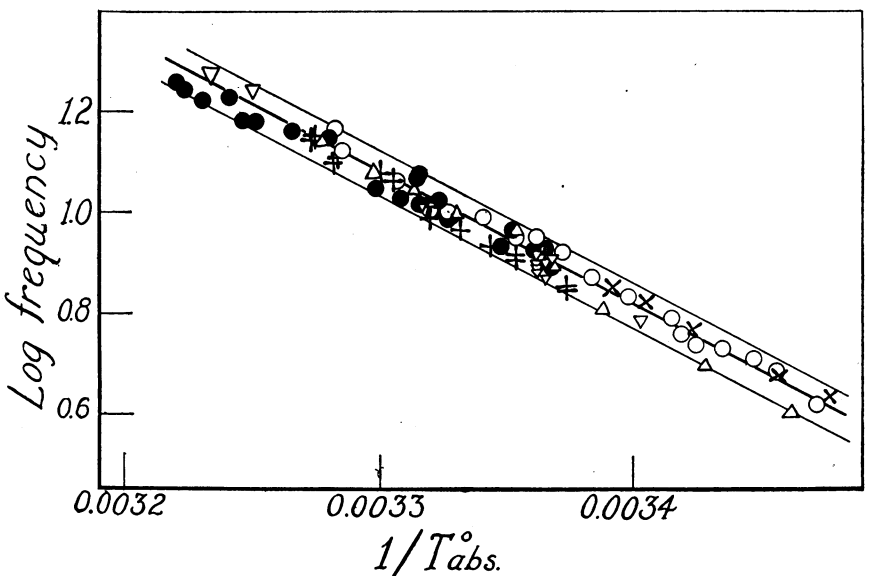

FIGURE 1

The relation between temperature (15° to 38°) and frequency of heart beat in *Bombyx* larvae. Each point is the mean of a series of closely concordant measurements. The several individuals (6) are represented by different symbols. The latitude of variation in heart beat at constant temperature is a constant fraction of the mean frequency for that temperature. This rule holds for a single individual and also for the observations made with different larvae similar in genetic and environmental history, though the degree of variation is probably not identical in all individuals.

as evidenced by the linear relation of *log frequency* to *reciprocal of absolute temperature*. The plotted points are each the mean of a series of determinations; in every case the degree of variation in a single series is very slight, in fact less than the diameter of the symbol. Therefore such variation is is evidenced is real variation. But it is clear that the individually determined points are sharply confined to a band centered upon the best-fitting line. The latitude of variation in frequency is at any temperature a fixed

fraction of the corresponding mean frequency. For the different individuals the amount of deviation is about the same.

The critical termal increment, μ, is in this case 12,200 calories. This agrees quantitatively with the increment for a number of other activities among arthropods[1] in which "nerve center" activity may be presumed to be the determining phenomenon.

Our purpose now, however, is not to dwell upon the meaning of the specific increment for heart rhythm, but to present the fact that when sources of variation are reduced to a reasonable minimum the velocities of biological phenomena are found to obey with exactitude the law of temperature influence upon irreversible chemical processes. The nature of the residual variations in velocity (frequently), as disclosed in this and other instances,[2] makes it important for precise analysis to secure numerous observations at close intervals of temperature.[5] Careful analysis of this type applied to representative cases makes it possible to interpret instances unavoidably involving more influential sources of variation.

A detailed discussion of the experiments, and a comparative account of thermal control of heart rhythm in various animals, will appear in *The Journal of General Physiology*.

[1] Crozier, W. J., *J. Gen. Physiol.*, **7** (123, 189); these PROCEEDINGS, **10** (461).

[2] Crozier, W. J., and Federighi, H., *J. Gen. Physiol.*, **7** (151); Crozier, W. J., and Pilz, G. F., *Ibid.* **6** (711).

[3] We are glad to thank Mr. L. R. Campbell for his assistance in caring for the larvae.

[4] Crozier, W. J., and Federighi, H., *Proc. Soc. Exp. Biol. Med.*, **21** (56); *J. Gen. Physiol.*, **7** (151); Glaser, O., *Ibid.*; *J. Gen. Physiol.*, **7** (177).

[5] The reasoning underlying the biological use of the Arrhenius equation for reaction velocities as function of temperature should warn against "averaging" observations from different individuals. Failure to avoid this practice has resulted in some curious errors in the literature of "temperature coefficients."

MICROCHEMICAL COLOR REACTIONS AS AN AID TO THE IDENTIFICATION AND CLASSIFICATION OF BRAIN TUMORS

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Cellular differentiation during embryological development in the last analysis is probably the result of chemical differentiation in the protoplasm of the cells. The nature of these differences is very obscure. We know in a general way that synthetic processes in the cells are condensations with dehydration, but the reasons for these processes resulting in a certain product in one cell, an entirely different product in another, and the steps through which the different results are achieved are but dimly surmised.