NOTE ON THE DISTRIBUTION OF CRITICAL TEMPERATURES FOR BIOLOGICAL PROCESSES.

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I.

A survey of data on the variation in velocities or frequencies of vital activities as controlled by temperature shows that in general there obtain rectilinear relationships between logarithm of velocity (or frequency) and reciprocal of absolute temperature. The constant \( E \) or \( \mu \), critical increment or temperature characteristic, which is defined by the slope of this relationship does not vary at random. Its values as determined from many series of observations upon diverse processes fall sharply into a small number of classes (Crozier, 1924). These classes must be presumed to correspond to real and distinct types of events in living matter. It has been suggested that they may in many cases be conceived to represent specific catalyzed reactions, which might thus become identifiable (Crozier, 1924, 1924-25, a).

Since it happens frequently, but not always, that two temperature characteristics apply to different portions of the temperature range, it is necessary to picture some form of interconnection between the corresponding processes. In part upon obvious general grounds, but also because of detailed evidence derived from study of a phenomenon for which no other interpretation seemed possible (Crozier and Federighi, 1923-24), it was assumed that the relationship might frequently be a catenary one, although certain other possibilities are by no means excluded (Crozier, 1924-25, b). From this standpoint one conceives, as determining the frequency of heart beat, for example, a series of rapid, linked, reactions, the velocity of each determined by the specific velocity of formation of its proper catalyst. The controlling step in such a series might then differ in two ranges of temperature according to the diverse effects of temperature upon the magnitudes of the several
velocity constants. This view affords a rational interpretation of the fact that, in suitable cases, experimental control of the temperature characteristic exhibited permits the uncovering, so to speak, of processes known to be allied but ordinarily concealed (Crozier and Stier, 1924-25, a and other series of experiments as yet unpublished).

Critical temperatures, defined as regions in which control changes from one underlying reaction to another, have been determined from the points of intersection of lines fitting portions of the temperature-velocity graphs (Crozier, 1924-25, a). But this is not the only type of critical temperature which must be recognized. In the respiratory rhythm of anurans (Crozier and Stier, 1924-25, b) there is discovered a type of break in the temperature graph which results from a change of frequency without change of temperature characteristic. This is best understood as due to a change in amount of the corresponding catalyst. It was pointed out (Crozier and Stier, 1924-25, b) that this type of effect, which occurs in several other well defined instances, and which is found to be subject to experimental control, presumably depends upon physical alteration of the catalytic material.

To these categories of critical temperatures there may be added temperatures (1) at which trigger effects (Crozier and Stier, 1924-25, a) appear; (2) at which sharp changes in behavior are apparent (Crozier and Federighi, 1924-25); and (3) at which phenomena cease to obey the rectilinear relationship between log velocity and $1/T^{\circ}$abs. The temperatures referred to under (3) represent high and low points beyond which the effect of temperature is only very slowly reversible; as a rule these points can be determined with fair precision.

The justification for putting together critical temperatures of the several classes enumerated is derived simply from the finding that the actual temperatures which clearly appear as most frequently critical in the different categories are as a matter of fact identical.

It thus becomes of interest to discover what regularities may be found in the occurrence of critical temperatures. Merely to refer such events to colloidal changes, as is sometimes attempted, usually explains nothing and serves merely as an apology for obscure thinking. We desire to know why the most frequently occurring critical temperatures have certain definite values, since this information should give clews as to the mechanisms of the critical effects.
The frequency of occurrence of critical breaks, as determined by examination of a large mass of relevant published material and of a number of investigations as yet undescribed, is exhibited in Fig. 1. This summary is published for the sake of its probable utility in connection with related discussions. To present in detail the numerous series of observations analyzed in its preparation would extend this note to unreasonable dimensions, for the literature concerned with temperature effects is very large.

![Graph of critical temperatures]

**Fig. 1. Distribution of critical temperatures.**

It is to be expected that a collection of random critical temperatures from a variety of sources should demonstrate the more frequent occurrence of those critical temperature regions which are in a real sense properties of protoplasm in general. Despite imperfections known to be present in the basic data, it is a fair conclusion that this expectation is met by the curve in Fig. 1. The graph rises to well defined modes. These do not occur at points exactly 5° apart, nor at 5°, 10°, . . . , as they might if unfairly weighted and distributed.
through a tendency of observers to work at temperatures so spaced. Moreover, a large number of the points are determined by the intersections of lines taken to provide for the same activity different values of \( \mu \) for different temperature ranges, and are thus independent of the particular temperatures at which observations were made. These latter cases by themselves yield modal critical temperatures identical with those evident in Fig. 1.

For the purpose of this summary the observed critical temperatures have been rounded off to the nearest degree. Results from independent series of readings by one observer upon the temperature relations of a single sort of activity (e.g., heart rate) in one kind of organism have been averaged. This procedure is legitimate, for in addition to uncertainties of observation it should be stated that in cases which have been most extensively studied, with homogeneous material, there is evidence of real but not extensive variation in critical temperature. Again, instances are available in which a critical temperature, as here defined, may be shifted under experimental treatment; these latter cases have been excluded from the present summary.

The individual entries contributed to Fig. 1 differ greatly in weight and precision of observational basis. The phenomena considered are very diverse, from growth of fungi to minimal critical temperatures for the hearts of mammals. The total number of cases is sufficiently large, however, namely 2861 to give real opportunity for manifestation of any significant tendency to form a unimodal frequency distribution. The positions of the peaks are not materially modified by other methods of grouping, and correspond with the positions of the critical temperatures as obtained from those series of observations judged on independent grounds to be qualitatively best. Where the numbers of instances begin to be adequate, each mode represents the peak of a frequency distribution.

The temperatures which may be given as the most frequently occurring critical temperatures, on the basis of Fig. 1, are: 4.5°, 9°, 15°, 20°, 25°, 27°, 30°. It is noteworthy that the frequency of occurrence is about the same for each of these points, except that at 4.5°, which is

\[ \text{1 Above 30° the available data become very difficult to interpret, because with tissues of many forms destructive effects in which the time of exposure is important are then commonly evidenced.} \]
low, and that for $15^\circ$, which is twice as great. The occurrence of a critical region in the neighborhood of $4^\circ$ to $5^\circ$ gives a very interesting suggestion for the further study of these points, both as to the meaning of the critical temperatures and of their distribution. This must for the present remain open.

III.

SUMMARY.

The critical temperatures at which irregularities appear in the relations between vital processes and temperature are not distributed at random. As based upon detailed knowledge of individual cases, and as derived from inspection of the frequencies of occurrence, these critical points are usually found to be in the neighborhood of $4.5^\circ$, $9^\circ$, $15^\circ$, $20^\circ$, $25^\circ$, $27^\circ$, $30^\circ$.

CITATIONS.


There is enforced by this finding the conception of critical temperatures as defining thermal zones within which particular reactions occurring in protoplasm are enabled to control the activities of the organism. Such limiting temperatures are clearly apparent in growth phenomena (Crozier, 1924–25, b; Bliss, 1925–26). The observations of Setchell (1915, 1920, 1925) have led him to a quite independent deduction of critical temperatures for the distribution of marine algae and other plants, which he has been able to trace to the thermal control of growth and fructification. The remarkable fact emerges that the critical temperatures assigned by Setchell are: $5^\circ$, $10^\circ$, $15^\circ$, $20^\circ$, and $25^\circ$. It is scarcely possible to regard the correspondence between Setchell’s results and those of the present paper as accidental.