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THE RELATIVE POSITION OF THE MAXIMA CONTRACTIONS OF THE AMPHIBIAN MUSCLE WHEN SUBJECTED TO VARIOUS RANGES IN TEMPERATURE

RALPH. L. PARKER

In the regular laboratory work in muscle-nerve physiology, it was noted that records obtained by subjecting frog muscles to various ranges of temperature did not exactly agree as to positions of maxima contractions with statements found in the texts, especially that of Howell.<sup>1</sup> At the suggestion of Dr. F. M. Baldwin a fairly large series of experiments has been carried out to determine the relative positions of maxima contractions of the gastrocnemius muscle of the frog under varying temperature conditions, and to compare the results thus obtained with those of other investigators. Two of the muscles died from being subjected to low temperatures so there were only twenty complete records. Many investigators have worked with this particular muscle and observed the effect of heat in other ways; duration of contraction at different ranges of temperature<sup>1, 10</sup>; the cause of heat rigor;<sup>3</sup> periods of irritability;<sup>5</sup> fatal maximum temperature at which a frog or exsected muscle will survive<sup>6, 8, 10</sup>. Howell, however, is the only one so far as I can find in the literature to make any statement concerning the position of the maxima contractions.

Fall or winter frogs of the species *Rana pipiens* were used and were obtained from a supply house in Chicago. Apparatus used was a muscle-lever, muscle-warmer with thermometer, bunsen burner, container for water bath, induction coil and key, and a rotary kymograph. All except the water container were of the Harvard type of instruments. The water container was of convenient size and made of galvanized iron. The exsected muscles were suspended within the muscle-warmer by means of a short wire terminating in hooks at each end. The opposite end from the muscle was attached to a wire hook on the short arm of the muscle-lever. The thermometer was placed in the muscle-warmer next to the muscle. The muscle-warmer was immersed in the solution within the container and then heated or cooled as was desired. A single stimulus was used of sub-maximal strength.

When the desired temperature was registered a stimulus was given, the record for that temperature labeled, and the drum turned a short space for the next stimulation.

A range of temperature from  $+10^{\circ}\text{C}$ . down through  $0^{\circ}\text{C}$ . to  $-7^{\circ}\text{C}$ . and then up through  $0^{\circ}\text{C}$ . to rigor caloris was used. It was found, however, that in order to reach the turning point below  $0^{\circ}\text{C}$ . it was necessary to change the temperature rapidly to prevent the muscle from being killed or to produce a period of no irritability. A cooling mixture of ice and salt was used as the means to produce the desired temperatures below  $0^{\circ}\text{C}$ . and when the turning point had been reached a bunsen burner was applied to increase the temperature. Records were taken at intervals of five degrees during the descent to  $0^{\circ}\text{C}$ .; below  $0^{\circ}\text{C}$ . they were obtained at each degree and on recovery the interval was usually taken each two degrees until rigor caloris was reached when the muscle became non-irritable.

There were no two muscles that responded alike throughout as would be expected but some were more or less similar or at certain points paralleled one another closely. As a whole the records of the muscles fell into one of the two classes; they showed either two maxima or three maxima points. For convenience the range of temperature was arbitrarily divided into four periods. The first period covered from  $+10^{\circ}\text{C}$ . to  $-7^{\circ}\text{C}$ .; the second one extended from  $-7^{\circ}\text{C}$ . to  $+20^{\circ}\text{C}$ .; the third period ranged from  $22^{\circ}\text{C}$ . to  $42^{\circ}\text{C}$ . and finally the rigor period from  $44^{\circ}\text{C}$ . to  $50^{\circ}\text{C}$ ., where the majority of muscles went into rigor caloris, with complete loss of irritability.\* The first maxima were found to fall into the first period, in the second came the second maxima, the third maxima appeared in the third period and the maxima of heat rigor in the fourth period. When only two maxima occurred they appeared in the first and third periods with the usual heat rigor maximum.

In the three-maxima class, when different individual records were studied, there seems to be two different points for the second maxima, one in the range from  $-5^{\circ}\text{C}$ . to  $-2^{\circ}\text{C}$ . and the other falling somewhere between  $+8^{\circ}\text{C}$ . and  $+16^{\circ}\text{C}$ . This might be accounted for in the latter case in some measure by exposure to the cold, since this might render the muscle non-irritable and a lag in response on recovery might result.

The first maxima of this group appeared between  $10^{\circ}\text{C}$ . and

\* In the following discussion the rigor maximum was not included as a maximum, for other influences enter in and thus it would not compare favorably with those which were stimulated by electricity. Rigor caloris is discussed in a later paragraph.

—3°C. and the third between 34°C. and 42°C. The two-maxima class produced the first maxima between 10°C. and —3°C. and the second, after going through the second period in a rather symmetrical curve, appears in the third period from 36°C. to 42°C. The range of minimum temperature with the three-maxima was —6°C. to —2°C. for the first one, 12°C. to 30°C. for the second and 40°C. to 48°C. for the third. With the two-maxima records the first minimum was from —5°C. to +14°C. and the second 42°C. to 46°C. (Table I).

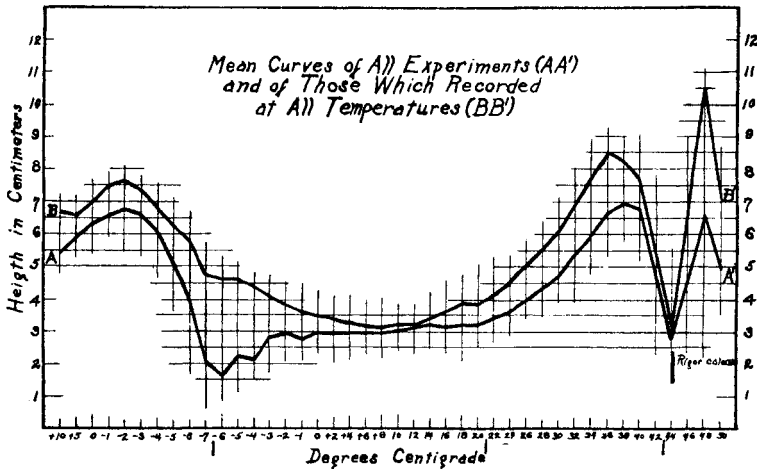


Fig. 53. Mean Curves of All Experiments and of Those Which Recorded at All Temperatures.

A-A' represents a mean curve of all muscle records and each temperature is plotted.  
B-B' represents a mean curve of all muscle records which recorded at all ranges of temperature and each temperature is plotted.

To obtain a better conception of how the results of the twenty experiments compared, several curves were made and are subjoined below; one of all the records when averaged, (Fig. 53, A-A'); one showing the average of those recorded at all ranges of temperatures (seven) (Fig. 53, B-B'); average of all three-maxima contractions (Fig. 54, 11-11); average of all two-maxima contractions (Fig. 54, 9-9); a typical three-maxima curve (Fig. 55, 10-10); and a typical two-maxima curve (Fig. 55, 22-22). It will be seen from the curve of all the records from the muscles (A-A') that three maxima appear, the first one at —2°C., the second at —2°C. and the third at 38°C. Rigor caloris began at 44°C. The curve of those registering at all temperatures (seven in number) is of the two-maxima type, the first at —2°C., the second at 36°C. Rigor caloris began at

44°C. (Fig. 53, A-A' and B-B'). Those individuals which had three definite maxima were averaged, and numbered eleven (Fig. 54, 11-11). The first maximum was at  $-1^{\circ}\text{C}$ ., the second at  $-3^{\circ}\text{C}$ . and the third at  $36^{\circ}\text{C}$ . Rigor calor $\acute{e}$ s began at  $42^{\circ}\text{C}$ . Nine, the remainder of the twenty experiments, fell into the two-maxima class (Fig. 54, 9-9). The first maximum appeared at  $-2^{\circ}\text{C}$ . and the other at  $36^{\circ}\text{C}$ . Rigor calor $\acute{e}$ s began at  $44^{\circ}\text{C}$ . A typical two-maxima curve (22-22) and a typical three-maxima (10-10) curve are shown in Fig. 55. Here, as in the former,

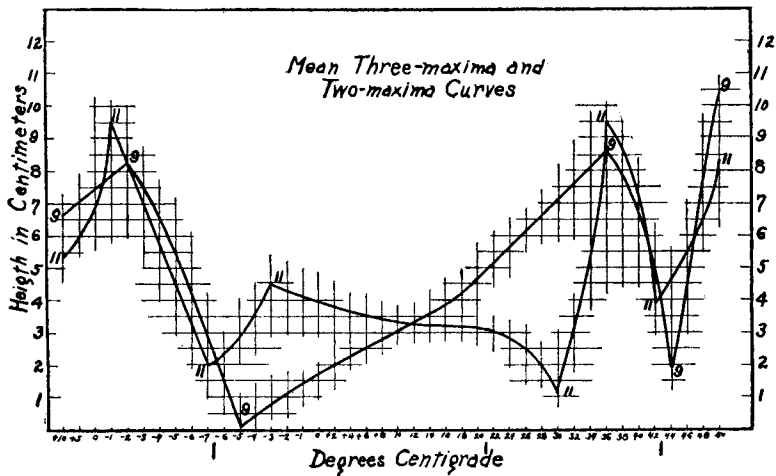


Fig. 54. Combined Mean Three-maxima and Two-maxima Curves.

11-11 represents a mean three-maxima curve which was plotted from the mean maxima and minima of the eleven which fell in this class.

9-9 represents a mean two-maxima curve which was plotted from the mean maxima and minima of the nine which fell in this class.

the first maximum appeared at  $-2^{\circ}\text{C}$ . and the other at  $38^{\circ}\text{C}$ ., while in the latter the first maximum is at  $-3^{\circ}\text{C}$ ., the second at  $-3^{\circ}\text{C}$ . and the third at  $40^{\circ}\text{C}$ . Rigor calor $\acute{e}$ s for (22-22) began at  $41^{\circ}\text{C}$ . and for (10-10) at  $43^{\circ}\text{C}$ .

The range of the first maxima for all curves was from  $-1^{\circ}$  to  $-3^{\circ}\text{C}$ . and fell in the first period. For the second maxima of all curves  $-3^{\circ}$  to  $-2^{\circ}\text{C}$ . was the limit and fell in the second period. The third maxima came from  $36^{\circ}$  to  $40^{\circ}\text{C}$ . and fell in the third period. Rigor calor $\acute{e}$ s began from  $41^{\circ}$  to  $44^{\circ}\text{C}$ . and its maxima was from  $48^{\circ}$  to  $50^{\circ}\text{C}$ .

Rigor calor $\acute{e}$ s maximum generally proximated the greatest maxima but when all were averaged it was slightly less than the greatest maximum. The greatest maximum measured 6.9 centimeters and that of rigor 6.6. In the individual cases, out of the

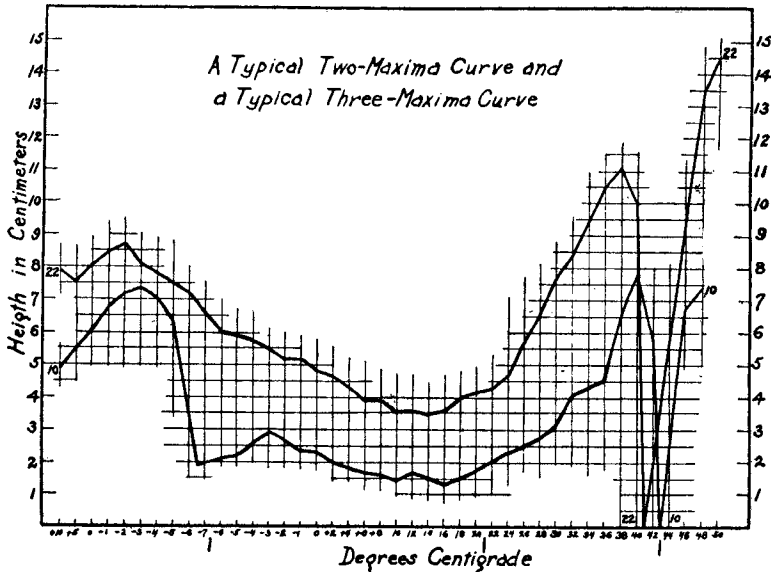


Fig. 55. A Typical Two-maxima and Three-maxima Curve. 10-10 illustrates a typical three-maxima curve which was plotted at every temperature. The numbers (10-10) denote the number of the experiment. 22-22 represents a typical two-maxima curve and each temperature is plotted. The numbers (22-22) as before denote the number of the experiment.

twenty there were twelve greater than the greatest maximum and eight less than it. For seven (B-B') which recorded at all temperatures it was 2.0 centimeters greater than the greatest maximum. As in the case of the conglomerate average (A-A'), rigor of the three-maxima curve was less than the greatest maximum. The two-maxima rigor maximum was greater as was that of B-B' and was 1.9 centimeters greater. It is, of course, rather difficult to evaluate results in terms of height of tracing, but comparative figures may have some value.

The only one to give any information on the subject is Howell<sup>1</sup> and he does not state where the information may be found or how it was obtained. I presume his statement of the position of the maxima applies to a series of experiments on individuals and is interpreted accordingly and is not based upon combined averages. Below is shown a table of results by several observers.

Table II shows the results when taken from all the curves as shown in figures 53, 54 and 55.

#### SUMMARY

When excised gastrocnemius muscle of the frog is subjected to a relatively low temperature ( $-7^{\circ}\text{C}.$ ) two and three maxima

TABLE I. TEMPERATURES OF MAXIMA AND MINIMA CONTRACTIONS

		FIRST PERIOD		SECOND PERIOD		THIRD PERIOD		FOURTH PERIOD	
		MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.
Three-maxima	Parker	+ 10° to - 3°C.	- 6° to - 2°C.	- 5° to - 2°C. + 8° to + 16°C.	12° to 30°C.	34° to 42°C.	40° to 48°C.	46° to 50°C.	
Two-maxima	Howell			5° to 9°C.	15° to 18°C.	26° to 30°C.	36° to 40°C.		
	Parker	10° to - 3°C.			- 5° to 14°C.	36° to 42°C.	42° to 46°C.	46° to 50°C.	
Other Observations	Marey					30° to 35°C.			
	Edwards					32.75° to 39.25°C.			
	Vincent and Lewis					38° to 40°C.			
	Carvallo and Weiss				25° to 30°C.	37° to 38°C.			

TABLE II. TEMPERATURES OF MAXIMA AND MINIMA CONTRACTIONS OF ALL CURVES.

PERIOD	1ST MAX.	1ST MIN.	2ND MAX.	2ND MIN.	3RD MAX.	3RD MIN.	4TH MAX.	4TH MIN.
First.....	-1° to -3°C.	-6½°						
Second.....		to -5°C.	-2° to -3°C.	+6°				
Third.....				to 30°C.	36° to 40°C.	41°		
Fourth.....						to 44°C.	48° to 50°C.	



appear. But on the other hand when the muscle was not subjected to such low temperatures ( $-4^{\circ}\text{C}.$  to  $-5^{\circ}\text{C}.$ ) in the first period and then was non-irritable for several changes in the range of temperature (about five) a third maximum appeared between the first and last.

The relative positions of the maxima contractions as I have found them in twenty experiments are as follows: The first maxima falls in the first period between  $-1^{\circ}$  and  $-3^{\circ}\text{C}.$ ; the second maxima falls between  $-2^{\circ}$  and  $-3^{\circ}\text{C}.$  of the second period; the third maxima falls between  $36^{\circ}$  and  $40^{\circ}\text{C}.$  of the third period; while that of rigor caloris is usually between  $48^{\circ}$  and  $50^{\circ}\text{C}.$  of the fourth period.

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#### EXPLANATION OF FIGURES

Short line between  $-7^{\circ}$  and  $-6^{\circ}$  is the limit of the first period,  $20^{\circ}$  and  $22^{\circ}$  is the limit of the second and  $42^{\circ}$  and  $44^{\circ}$  is the limit of the third period.

The ordinates represent the height of the tracing of the muscle lever in centimeters. The abscissa denote degrees of temperature Centigrade.