

RHYTHMICITY IN THE PROTOPLASMIC STREAMING OF A SLIME
MOLD, *PHYSARUM POLYCEPHALUM**

I. A STATISTICAL ANALYSIS OF THE ELECTRIC POTENTIAL RHYTHM

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ABSTRACT

The electric potential difference (1 to 15 mv.) between two loci of the slime mold connected with a strand of protoplasm changes rhythmically with the same period (60 to 180 seconds) as that of the back and forth protoplasmic streaming along the strand. Generally some phase difference is observed between them. Periods of the electric potential rhythm show a Gaussian distribution. Amplitudes give a somewhat different distribution curve. Wave forms are not always simple harmonic ones, but are distorted more or less. However, auto-correlation analysis proves that there is a dominant rhythm of a nearly constant period which coincides with the mean period of the Gaussian distribution curve. Calculations made on an assumption that the electric potential rhythm is the result of many elementary rhythms (*i.e.*, same periodicity, arbitrary phase angles) distributed throughout the plasmodium, give a satisfactory coincidence with the observed distribution for the amplitude. The predominance of a rhythm of a nearly constant periodicity suggests the existence of well organized interactions among components of a contractile protein network, the rhythmic deformation of which is supposed to be responsible for the protoplasmic streaming and for the electric potential rhythm.

One of the most characteristic properties of the plasmodium of the slime mold, *Physarum polycephalum*, is that it shows a remarkable back and forth protoplasmic streaming along a protoplasmic strand. Because of this typical pattern of protoplasmic streaming, as well as its large size and ease of culturing, the slime mold can be used as good material in studying the mechanism of protoplasmic streaming. Many interesting studies have been published recently on the biophysics and biochemistry of this organism.

The electric potential difference between two loci of the slime mold connected with a strand of protoplasm changes rhythmically with the same period as that of the back and forth protoplasmic streaming along the strand (Kamiya and Abe, 1950). The rhythmic change in the potential occurs whether

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the flow through the connecting strand is allowed to take place or is stopped by means of local blocking of the strand by application of a balancing pressure or CO₂ (Kamiya and Abe, 1950). On the other hand, an electric potential difference (0.01 to 4.0 volts) of short duration applied externally along the plasmodium did not produce any noticeable effects on the wave pattern of the rhythm of protoplasmic flow (Kamiya and Abe, 1950). Therefore, the electric potential rhythm of this organism is not the direct result of the protoplasmic flow (*e.g.* streaming potential), nor is it the direct cause responsible for the flow (*e.g.* electrophoresis). It is more reasonable to suppose that the electric potential rhythm is related to an innate mechanism which brings about the protoplasmic streaming. The author intends in this report to analyze the electric potential rhythm statistically.

Material

The plasmodium of *Physarum polycephalum* was used throughout the experiment. Most of the pieces for my preparations were taken from the tips of the plasmodia that had spread out over a wet filter paper in a Petri dish (30 cm. in diameter, 5 cm. in depth). At the center of the culture there was a generous supply of oatmeal (Camp, 1936). The culture was kept at about 20°C. in an incubator. By replacing remnants of oatmeal which became dirty with slime and bacteria with a fresh supply of oatmeal every day, we could have kept the culture in good condition for months. Growth and spreading, however, changed with the age of the culture. There were also some differences in the strength of flow, its velocity, and its period among the small pieces in the different preparations.

Apparatus

A vessel which is shown in Fig. 1 was used for measuring the electric potential difference between two parts of the plasmodium. This vessel which is made of glass was first used by Kamiya and Abe (1950) to study the strength of protoplasmic streaming of this organism. The vessel consists of two compartments, each with two arms, one of which is led to a direct current amplifier *via* a calomel electrode and the other of which is opened to the air. Above the partition between these two compartments, there is a thin channel 0.5 mm. in depth and in width. A piece of plasmodium (3 to 5 mm. in diameter) taken from the tip of the culture is placed on agar containing 0.001 M KCl in each of the two compartments. A protoplasmic strand connecting these two plasmodia is placed in the channel and sealed with white vaseline. Protoplasmic streaming here is observed with a microscope. Each compartment is covered with a glass plate (Fig. 1). The potential difference between two plasmodia was amplified by a direct current amplifier and was recorded with an electronic recorder (Yokogawa Electric Works, E. R. 121 type). The velocity of indication of this recorder is 5 seconds per full scale (20 cm. in length). However, as the recording was done, generally, within one-fifth of the full scale, possible errors arising from retardation in recording were negligible in our experiments in which potential rhythms of about 90 seconds in period were studied. Input impedance of the amplifier is more than 50 megohms, which

is large enough for the recording of the electric potential of this organism, as the resistance of the preparation is generally lower than 5 megohms. The stability of the amplifier was adequate, showing a zero point drift of less than 1 mv. in 10 hours.

RESULTS

At first we define the sign of the electric potential difference in such a way that the curve comes downwards when potential at *B* is higher than that at *A* and comes upwards in the reverse case. The direction of protoplasmic streaming along the connecting strand is shown with upward arrows at the

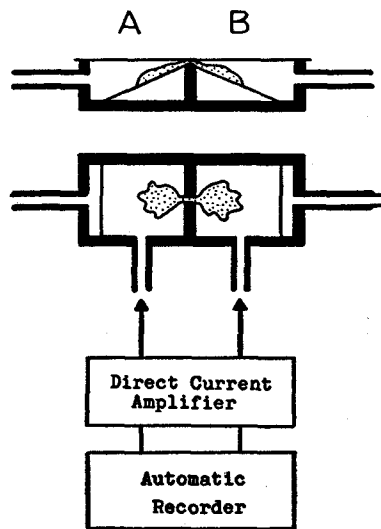


FIG. 1. A vessel for measuring the electric potential rhythm of a slime mold, *Physarum polycephalum*.

time when it changes from $A \rightarrow B$ to $B \rightarrow A$ and with downward arrows at the time when it changes from $B \rightarrow A$ to $A \rightarrow B$.

One example of the time course of the electric potential rhythm after placing the sample in the vessel is shown in Fig. 2. At the early stage, the rhythm does not appear. After a while the rhythm appears, though it contains many irregularities. As the streaming along the strand becomes vigorous the electric potential rhythm also grows. Such a time course is observed in every sample, although period and amplitude generally differ, to some extent, among the samples from different cultures or from the same culture at different ages.

The curve itself bears a striking resemblance to brain waves, except for its much longer period and comparatively large amplitude. The electric potential rhythm is not always a simple harmonic one, but contains some irregu-

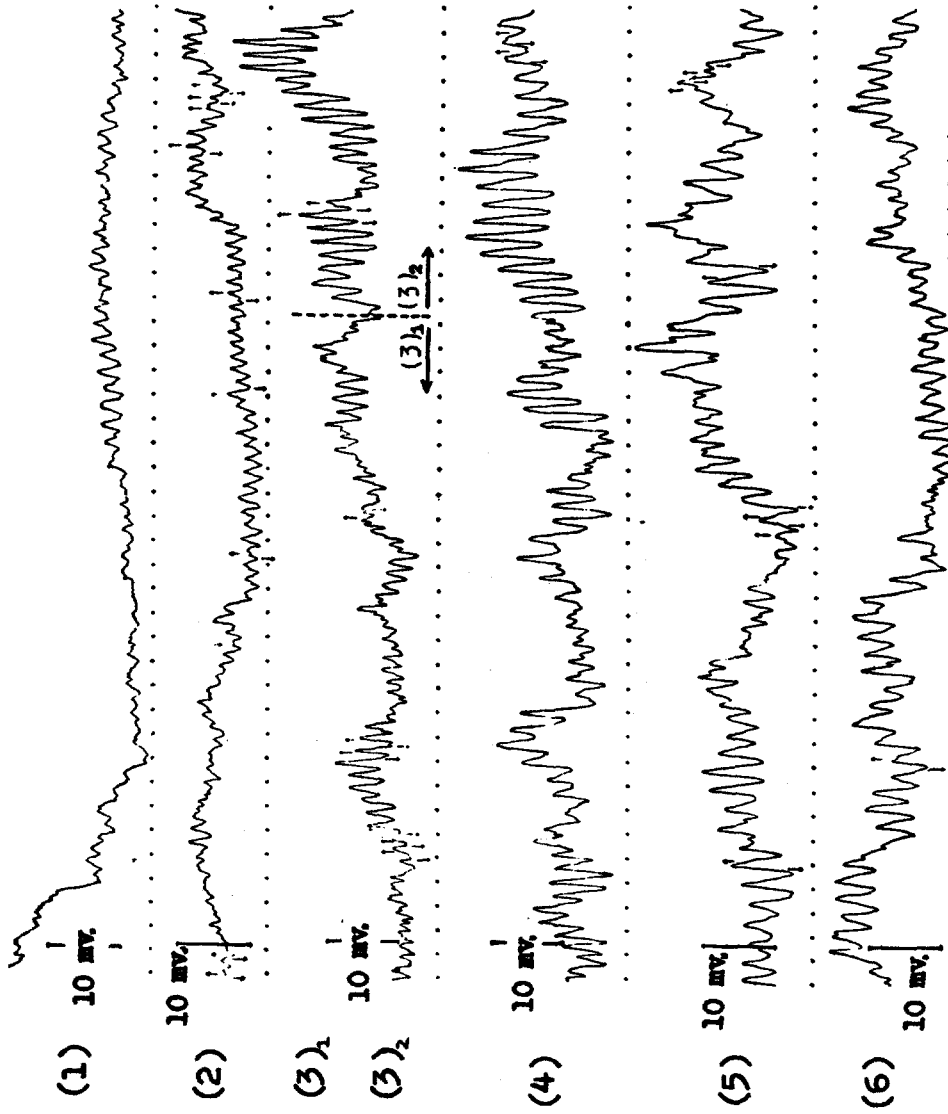


FIG. 2. One example of time courses of the electric potential rhythm after placing the plasmodium in the vessel shown in Fig. 1. At 20°C. **Time Markers, 2.5 min.**

larities. In this case, however, protoplasmic streaming maintains a close correlation with the potential rhythm. In Fig. 2 the arrows which show the time when flow changes its direction were added in only a few places to avoid complexity in the figure. Protoplasmic streaming does not change its direction at the time when the potential difference changes its sign, but usually a certain amount of phase difference is observed between them. In addition to this potential rhythm of about 1.5 minutes in period, potential drifts of much longer periods are generally observed.

For convenience, we can define the period of the electric potential rhythm as the time interval between two adjacent troughs and the amplitude as the vertical distance from the top of a peak to the line connecting adjacent troughs.

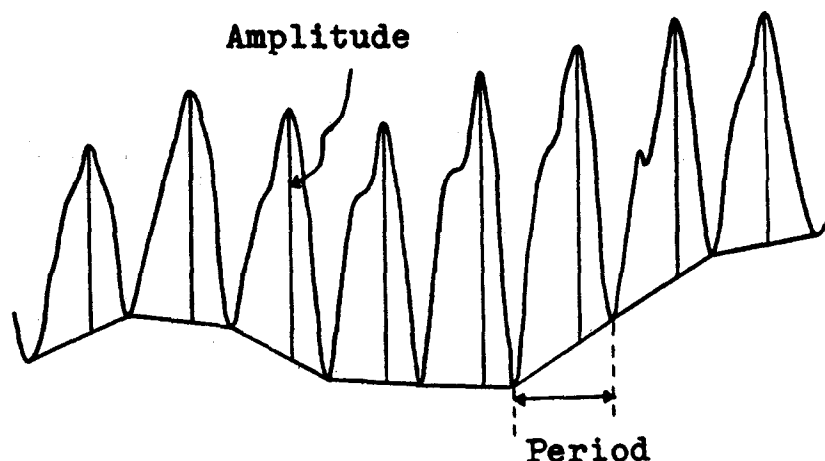


FIG. 3. Definitions of the period and the amplitude of the electric potential rhythm.

(Fig. 3). Sometimes it may be difficult to determine the period accurately when the wave pattern is much distorted. In such cases each time interval when the flow changes its direction can be referred to.

Amplitude and wave form of the potential rhythm are not constant, but change from time to time. The period also is not always constant throughout its time course (Fig. 2).

It is necessary to use a great many waves in order to obtain an accurate distribution curve for the period or for the amplitude. However, growth or development of this organism during an experiment may change its physiological condition and this will bring about, more or less, changes in the distribution curves. In Fig. 2 we can divide the potential rhythms, tentatively, into two groups: one group is from the middle of line 1 to the middle of line 3 where the amplitudes of the rhythms are evidently small, and the other is

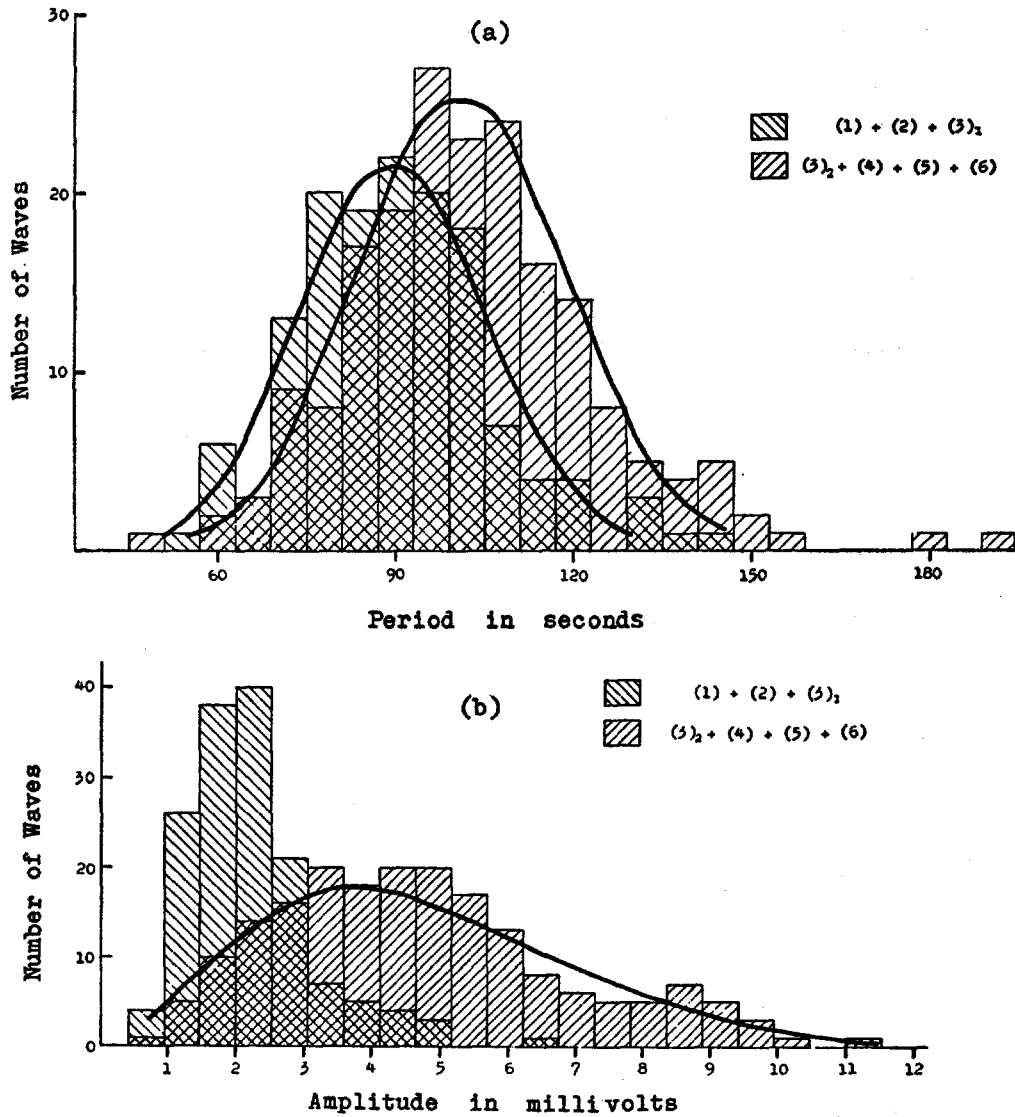


FIG. 4. Distribution curves for the period and the amplitude of the electric potential rhythm are shown with histograms. The curve drawn for the amplitude distribution was calculated with Equations (9) to (11). $\bar{A} = 4.76$ mv., $A_m = 3.8$ mv., $h = 0.186$ mv.⁻¹. The calculation was made only for (3)₂, (4), (5), and (6) in Fig. 2 when a steady state is supposed to be attained.

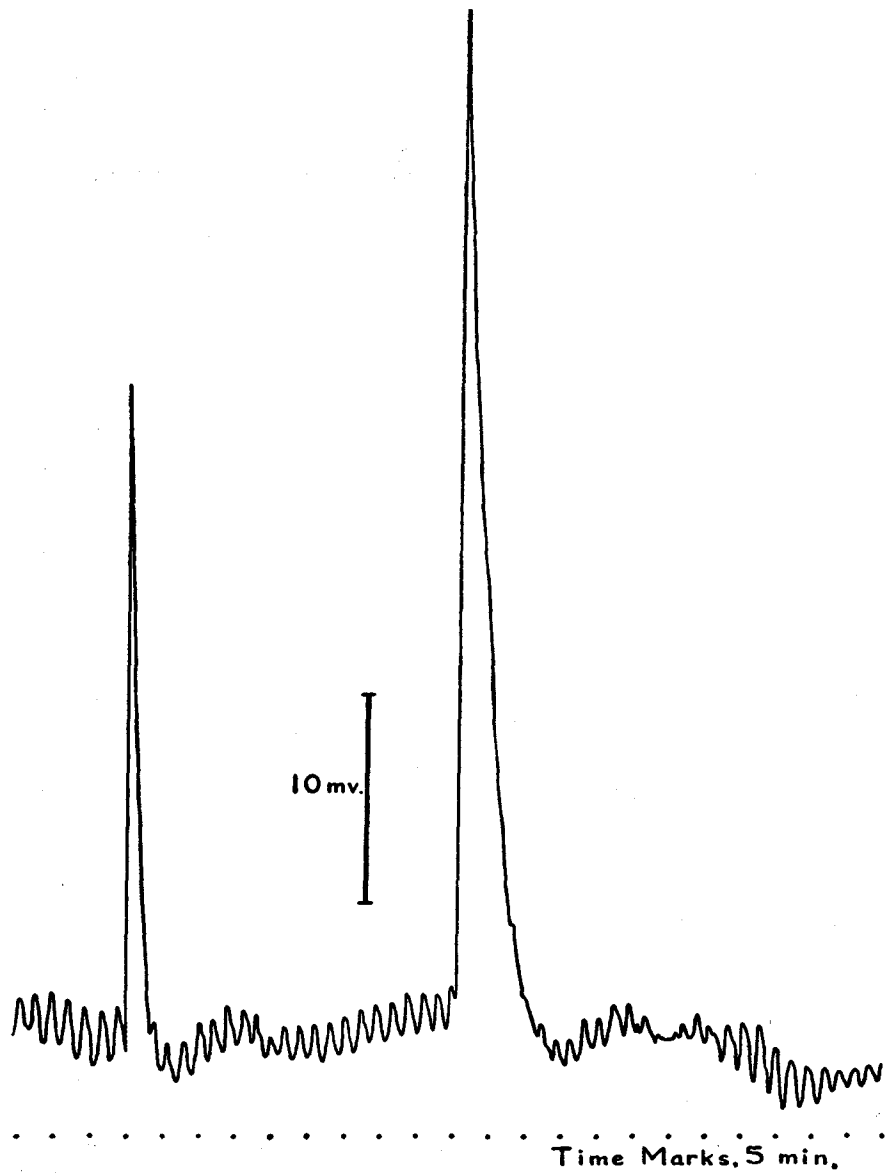


FIG. 5. Injury potentials brought about by piercing or by cutting one part of the plasmodium. The height of injury potential seems to depend on the magnitude of injury to the plasmodium, but is generally less than 90 mv. At 14.5°C.

the rest, where the amplitudes are comparatively larger than those of the first group. Plotting the number of waves of a given period against the period, we can get two Gaussian distribution curves (Fig. 4 *a*). With regard to the amplitude, the distribution curve is somewhat different (Fig. 4 *b*).

If the plasmodium at *B* is pierced or cut by a fine glass rod, an injury potential of -90 mv. or less can be observed (Fig. 5). This injury potential, however, does not last long, as in the case of muscle fibers, nerve cells, or many other cells, for the electric potential of this organism recovers its initial value in a few minutes. This recovery phenomenon can be explained by assuming that a new protoplasmic membrane has been formed at the injured surface (Diannelides and Umrath, 1953; Tauc, 1953, 1954). The electric potential rhythm continues after and probably during the occurrence of the injury potential.

From these results, we can assume that the potential difference across the protoplasmic membrane of the plasmodium consists of two terms. One is the usual static membrane potential of about 90 mv., which corresponds to the injury potential and the other is the rhythmic potential change which is closely related to the mechanism of protoplasmic flow. Accordingly, the potential difference across the membrane of plasmodium at *A* and at *B* can be expressed by equations (1) and (2) respectively.

$$E_A = (e_A)_o + a_t \cdot \sin(\omega t + \alpha_t) \quad (1)$$

$$E_B = (e_B)_o + b_t \cdot \sin(\omega t + \beta_t) \quad (2)$$

The first terms in these equations correspond to the static membrane potentials and the second terms correspond to the rhythmic potential changes of each plasmodium. Usually, the rhythmic potential changes at *A* and at *B* do not occur in phase. Therefore, we distinguish these by adding phase angles α_t and β_t in these equations. As shown in Fig. 4 *a* the period of the potential rhythm fluctuates around an average period; *i.e.*, T_o (angular velocity ω_o is 2π times reciprocal of T_o). Accordingly, we can suppose that the angular velocity of the potential rhythm takes, at a time, a value $\omega_o + \Delta\omega$, in which $\Delta\omega$ stands for deviations from the average angular velocity. ω is not necessarily equal at *A* and at *B*. Probably, the amplitudes, a_t and b_t , also change with time.

The potential difference actually observed by means of the experimental arrangement shown in Fig. 1 is the difference between these two potential differences; *i.e.*, (1) $-$ (2) (Fig. 6). If we regard ω as a random variable which is independent of time and consider that random deviations from ω_o (*i.e.*, $\Delta\omega$) are involved in fluctuations of phase angles α_t and β_t (*i.e.*, a frequency-modulated wave can be treated as a phase-modulated wave), this quantity can be expressed with equation (3).

$$\begin{aligned}
 \Delta E = E_A - E_B &= \{(e_A)_o - (e_B)_o\} \\
 &\quad + a_t \cdot \sin(\omega_o t + \Delta\omega \cdot t + \alpha_t) - b_t \cdot \sin(\omega_o t + \Delta\omega' \cdot t + \beta_t) \\
 &= \{(e_A)_o - (e_B)_o\} + c_t \cdot \sin(\omega_o t + \Delta\omega'' \cdot t + \gamma_t) \\
 &= \{(e_A)_o - (e_B)_o\} + c_t \cdot \sin(\omega t + \gamma_t)
 \end{aligned}
 \tag{3}$$

Again, angular velocity (ω) and amplitude (c_t) are quantities which vary randomly in time around mean values.

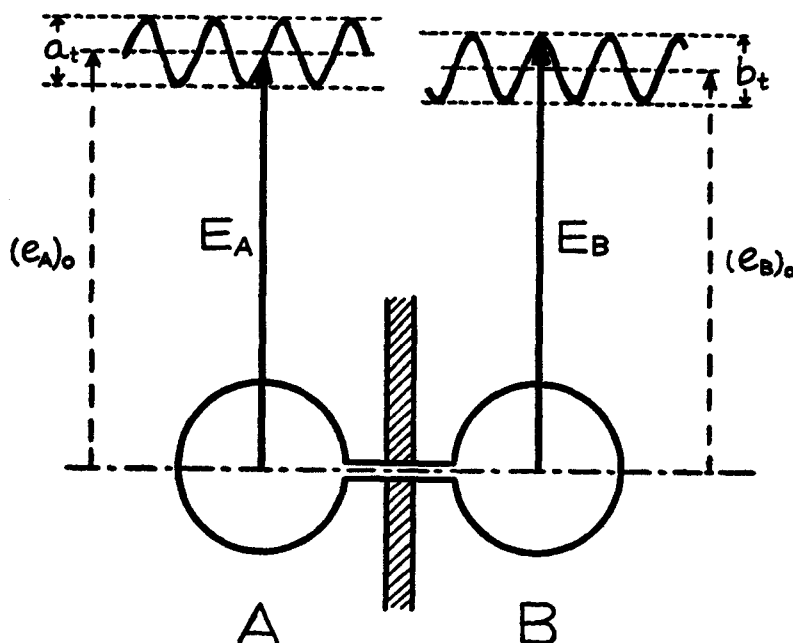


FIG. 6. A diagram of the electric potential difference of a slime mold, *Physarum polycephalum*, placed in the vessel shown in Fig. 1. $(e_A)_o$ is the static membrane potential and a_t is the amplitude of the rhythmic potential change and E_A is the resultant electric potential change of the plasmodium at A. $(e_B)_o$, b_t and E_B at B have meanings similar to those of A. The observed electric potential change is the difference between E_A and E_B .

The potential rhythm actually observed in Fig. 2 corresponds to the second term in equation (3). The first term in equation (3) corresponds to the difference between the static membrane potentials across the plasmodium at A and at B. This quantity is not always constant but changes from time to time with much longer period as shown in Fig. 2. Such potential drifts are brought about by a tendency of the plasmodium to go from A to B or from B to A in entirety. It was observed actually that the duration of flow in one direction was more vigorous and a few seconds (2 to 20 seconds) longer than

that of reverse direction at the time when such potential drifts occurred. At present we should like to consider only the rhythmic potential change.

Autocorrelation Function of the Electric Potential Rhythm.—In order to analyze the potential rhythm statistically, we must look for its autocorrelation function first. This method is generally used in order to find some hidden periods or regularities in a curve which contains many irregularities (*e.g.* seismic waves, solar noises, etc.). As mentioned above, our chief concern is with the potential rhythm, not with the potential drift of much longer period. It is desirable to eliminate the contribution of the latter. This can be done by drawing a line which divides the curve of potential rhythm in such a way that the area covered by a rhythm above the line is equal to that of the adjacent rhythm below the line and then replotting the potential rhythm against this line. Three representative curves replotted with such a treatment are shown in Fig. 7. There are three cases: (*a*) the rhythm is comparatively regular, (*b*) it is more or less distorted, (*c*) it contains many irregularities. In (*a*) and (*b*) the plasmodium kept a discal or fan-shaped form, while in (*c*) it extended so widely as to form a network of protoplasmic threads. If we call the function representing this curve $f(t)$, the autocorrelation function $R(\tau)$ is the time average of $f(t) \cdot f(t + \tau)$ and can be defined by equation (4).

$$R(\tau) = \overline{f(t) \cdot f(t + \tau)} = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T f(t) \cdot f(t + \tau) dt \quad (4)$$

Practically, the integral in equation (4) can be substituted for by the following summation:

$$R(m\Delta) = \frac{1}{N - m} \sum_{n=1}^{N-m} f_n \cdot f_{n+m} \quad (5)$$

Here $f(t)$ is given at a definite time interval, $t = 0 \sim T$, and its values at small time intervals $\Delta = T/N$ are f_1, f_2, \dots, f_N .

If we plot $R(\tau)$ against τ , we get the curves shown in Fig. 8. These curves do not damp so quickly as do those of seismic waves or noises. When the plasmodium does not extend too widely, the curve of the autocorrelation function $R(\tau)$ against τ shows a predominant period (Fig. 8 *a* and 8 *b*). One thing which should be noted here is that the period obtained with this process coincides with the average period T_0 of the original curve (Fig. 7). On the other hand, the curve for the autocorrelation function is generally complex, when the plasmodium extends so widely as to form a network of protoplasmic threads (Fig. 8 *c*). Such a situation is generally attained about 10 hours or more after placing the sample in the vessel. In this case the potential rhythm is not single, but contains several rhythms of different periodicities.

These results enable us to conclude that a potential rhythm of a definite

periodicity is dominant in the plasmodium so long as it does not extend too widely. However, when the plasmodium does extend so widely as to form a network of protoplasmic threads, several dominant rhythms of different periodicities can coexist in a plasmodium.

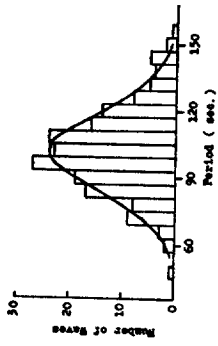
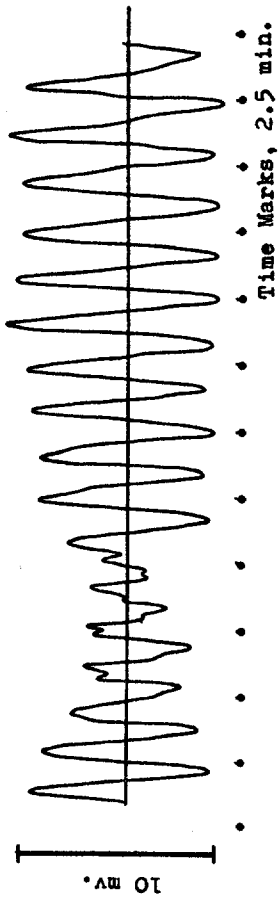
Period and Amplitude Distribution of the Electric Potential Rhythm.—From the analysis made above, it is clear that there is a dominant period in the electric potential rhythm so long as the plasmodium does not extend too widely. Fluctuations in the wave form can be regarded as originating from labile changes in phase angles, α_t and β_t , and from deviations of the period from its mean period. In other words, the measured period of the potential rhythm fluctuates around a dominant period (T_o), resulting in a Gaussian distribution for the periods.

In a record such as Fig. 7, the changes in phase and amplitude have an apparent progressive temporal change over many minutes. When the instantaneous periods and amplitudes are measured and plotted as in Fig. 4 *a, b*, such apparent regularities in the temporal changes of phase angle and amplitude are neglected. Further analysis of the temporal sequence of the deviations from the mean of the phase and amplitude would be needed to indicate whether these are randomly distributed in time. The following theory relates to an electromechanical model that accounts only for the probability distributions in Fig. 4 *a, b*, and assumes that the recorded fluctuations are randomly distributed in time.

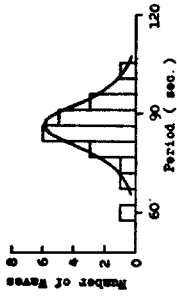
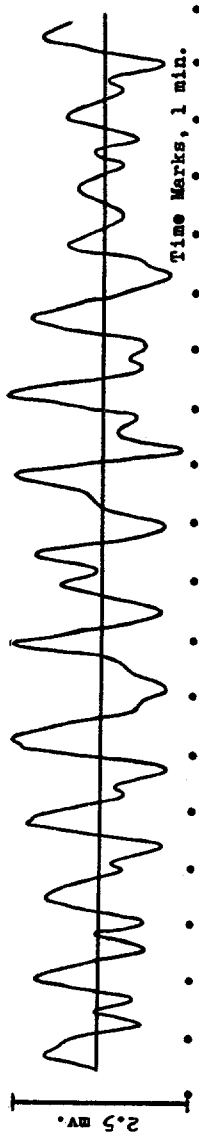
According to Tasaki and Kamiya's experiment (1950), an electric stimulus to the plasmodium brings about only local electric response, which does not propagate to other regions. Also, the electric potential difference between any two places in a plasmodium shows a rhythmic change (Tauc, 1954). Therefore, the electric potential changes at different parts of the plasmodium can be summated. Referring to these results we can assume that the electric potential rhythm of the plasmodium is a resultant of a vast number of elementary rhythms, the periods of which are assumed nearly constant (*i.e.*, $T_o = 2\pi/\omega_o$), but their phases can take arbitrary values. Such elementary rhythms are supposed to be the results of contraction and expansion of each submicroscopic network constructed by the contractile proteins in the plasmodium. The phase angle of each elementary rhythm is assumed to vary in time about a mean value. Furthermore, one may assume that the amplitude of each elementary rhythm is constant. Such a random variation of phase of each elementary process will produce a Gaussian distribution of period and/or amplitude of the recorded sum of the elementary processes. Of course, the amplitude of each elementary process may also vary randomly in time, but this additional variation would not be necessary to account for the observed fluctuations.

Such elementary rhythm can be expressed, generally, with vectors in a

(a)



(b)



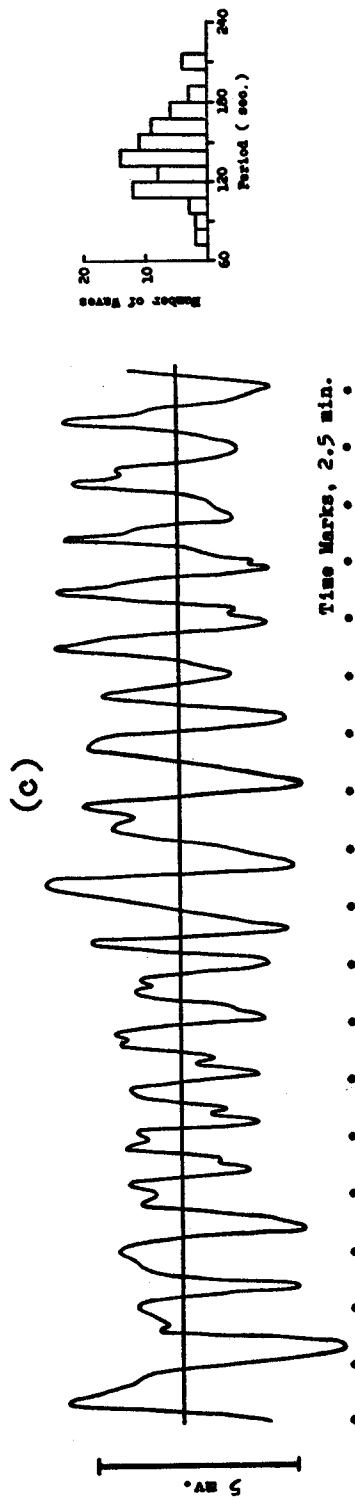


FIG. 7. Three representative cases of the electric potential rhythms. These examples are from the samples from different cultures. In (a) the electric potential rhythm is comparatively regular (at 20°C.). In (b) it is more or less distorted (at 24°C.). In these two cases the plasmodium did not extend too widely. In (c) the plasmodium extended so widely as to form a network of protoplasmic strands (at 23.5°C.). In these figures contributions of slow electric potential drifts are eliminated. See text. The electric potential rhythm shows not only distortions in wave form but wide distribution in the period. Distributions of the periods are added at the right hand respectively.

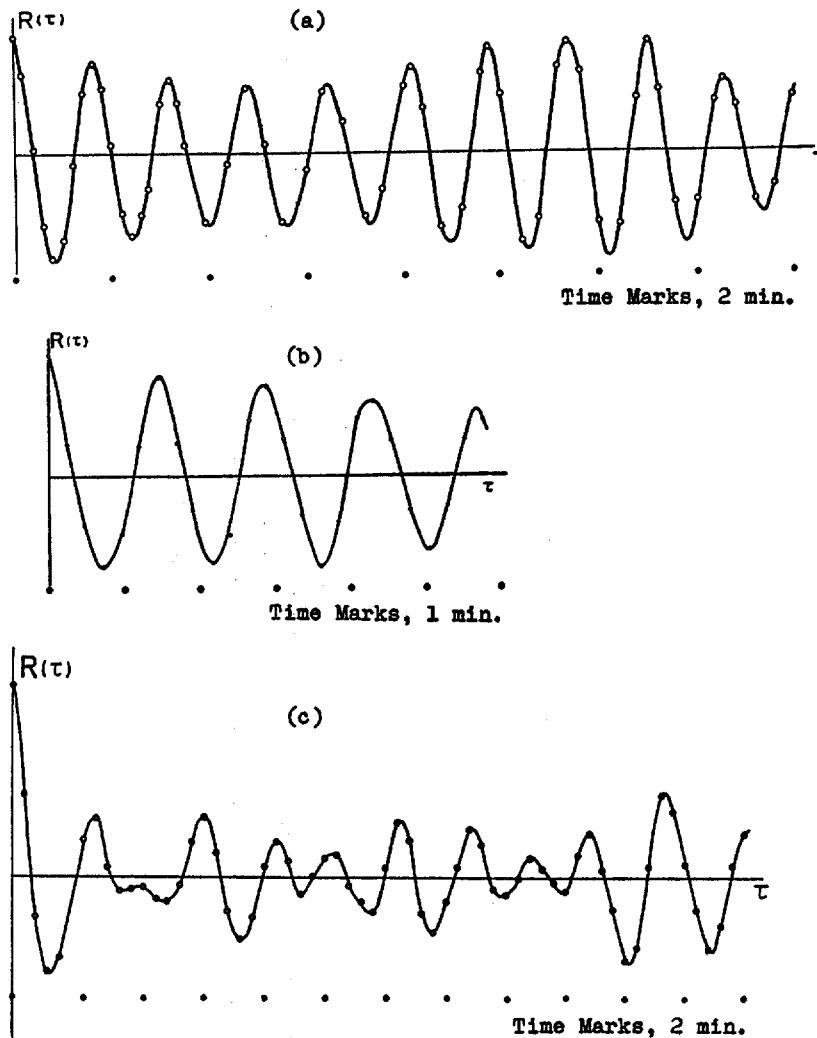


FIG. 8. Autocorrelation curves for the three examples shown in Fig. 7 are plotted against amounts of time lapse, τ . When the plasmodium does not extend too widely, the curve shows the dominance of a definite periodicity (Figs. 8 a and 8 b). On the other hand, when it extends so widely as to form a network of protoplasmic strands (Fig. 8 c), several rhythms of different periodicities can coexist in the plasmodium.

complex plane; *i.e.*, $z_i = x_i + jy_i$ ($j = \sqrt{-1}$). Then the resultant rhythm is expressed as follows:—

$$Z = X + jY, \quad X = \sum_i x_i, \quad Y = \sum_i y_i \quad (6)$$

The absolute value of the vector corresponds to the amplitude of the rhythm. As the phase of each elementary rhythm is assumed to vary in time, the magnitude and sign of the components of the elementary vector, x_i and y_i , change in a random way. Consequently, the phase and amplitude of the summed elementary rhythms vary statistically, the mean period indicating an inherent constant frequency. Thus

$$\begin{aligned} Z &= \sum_i (x_i + jy_i) \\ &= \sum_i a_i e^{j[\omega t + \theta_i(t)]} \end{aligned} \tag{7}$$

Speaking exactly, ω is a random variable which fluctuates around a mean value ω_0 (*i.e.*, Gaussian distribution). Therefore, equation (7) can be written in a form such as the second terms in equations (1) to (3), in which ω varies randomly in time around ω_0 . However, if we suppose that random deviations from ω_0 (*i.e.*, $\Delta\omega$) are involved in the fluctuations of phase angles, equation (7) can be rewritten as follows:—

$$\begin{aligned} Z &= e^{j\omega_0 t} \sum_i a_i e^{j\theta'_i(t)} \\ &= e^{j\omega_0 t} \sum_i a_i (\cos \theta'_i(t) + j \sin \theta'_i(t)) \end{aligned} \tag{8}$$

The first term on the right corresponds to the common rhythm, of angular velocity ω_0 , and the phase angle $\theta'_i(t)$ varies randomly in time about a mean value. (As mentioned above, a_i could also vary randomly in time, but this is not necessary.)

Thus, the magnitude and sign of the components of an elementary vector, $x_i + jy_i$, change in various ways. For such a situation Gauss's theory of errors can be applied. Then, the probability that X is between X and $X + dX$ or Y is between Y and $Y + dY$ can be expressed by $\frac{h}{\sqrt{\pi}} \cdot e^{-h^2 x^2} \cdot dX$ or $\frac{h}{\sqrt{\pi}} \cdot e^{-h^2 y^2} \cdot dY$ in which h is a constant. Accordingly, the compound probability that X is between X and $X + dX$ and that Y is between Y and $Y + dY$ is the product of these two probabilities; *i.e.*, $\frac{h^2}{\pi} \cdot e^{-h^2(x^2+y^2)} dX \cdot dY$. If we express this in polar coordinates, the compound probability is $\frac{h^2}{\pi} \cdot e^{-h^2 A^2} \cdot A \cdot dA \cdot d\Theta$, in which A is the amplitude and Θ is the phase angle of the resultant vector. Integrating this from 0 to 2π about Θ , we can get the probability that A is between A and $A + dA$ as follows:—

$$WdA = 2h^2 A e^{-h^2 A^2} dA \tag{9}$$

This equation was first derived by Motokawa and Mita (1942) and is known as the law of amplitude in electroencephalography. The arithmetical mean

value of the amplitude, \bar{A} , which is calculated with the equation $\bar{A} = \sum_i n_i A_i / N$ (n_i is the number of waves whose amplitude is A_i and N is the total number of the waves) can also be derived from equation (9) as follows:—

$$\bar{A} = 2h^2 \int_0^{\infty} A^2 e^{-h^2 A^2} dA = \sqrt{\pi}/2h \quad (10)$$

The most frequent amplitude, A_m , or “mode” of the amplitude distribution curve can be calculated from equation (9) using a condition $dW/dA = 0$.

$$A_m = 1/h \cdot \sqrt{2} \quad (11)$$

\bar{A} and A_m are related to each other by means of the following equation

$$A_m/\bar{A} = \sqrt{2/\pi} = 0.798 \quad (12)$$

At a time interval at which a steady state is supposed to be attained (*i.e.*, (3)₂ + (4) + (5) + (6) in Fig. 2), the calculation made with equations (9) to (12) gives a satisfactory coincidence with the experiment (Fig. 4 *b*). The calculation, however, does not give a satisfactory coincidence for the electric potential rhythms at the early stage after the plasmodium has been placed in the measuring vessel (*i.e.*, (1) + (2) + (3)₁ in Fig. 4 *b*). Perhaps, this may be due to the fact that too many rhythms of smaller amplitude are counted in the histogram and that the assumptions made in the calculations cannot hold for such a transitional stage.

Growth or development of the plasmodium which is supposed to occur in the time course (*i.e.*, 8 hours) of the electric potential rhythm will change the physiological condition more or less and the mean period (T_o) shows, generally, a tendency to increase to some extent (Fig. 4 *a*).

DISCUSSION

According to Kamiya and Abe's experiment (1950) and the results reported above, it is quite reasonable to suppose that the electric potential rhythm is closely related to an innate mechanism which brings about the protoplasmic streaming along the strand.

Glancing at the curve of the electric potential rhythm, we notice that its period, amplitude, and wave form are not constant, but change from time to time. Analyzing the electric potential rhythm with the autocorrelation function method, we find that a rhythm of nearly constant period is dominant. This result enables us to assume that the potential rhythm can be expressed by the second terms of equations (1) to (3), the period of which varies randomly in time around a mean value (T_o) determined with autocorrelation analysis (Fig. 8).

Kamiya (1942, 1953) found waves two, three, and four, etc. times the fundamental frequency by Fourier type analysis, although he did this on the periodic changes in balancing pressure necessary to stop the flow along the connecting

strand, and not on the electric potential rhythm. This information may be useful for correlation with visible events at various parts of the plasmodium. However, actual electric potential rhythm is not constant, but shows an apparent progressive temporal change and randomness over many minutes (Fig. 2). A Fourier type analysis alone is not sufficient to analyze such a rhythm.

In any event, the fact that a dominant rhythm of a definite periodicity exists which corresponds to the mean period of the Gaussian distribution curve seems to show that each portion of the protoplasm of the slime mold does not behave independently, but that there is an organization among them. However, when the slime mold extends so widely as to form a network of protoplasmic strands, several dominant rhythms of two or three different periodicities can coexist in a slime mold, and one example is shown in Fig. 8 *c*.

With regard to the mechanism of protoplasmic streaming, the author takes the following viewpoint which has been discussed by several authors. The protoplasmic streaming is maintained by the contractile proteins in the protoplasm (Seifriz, 1942, 1943; Goldacre and Lorch, 1950; Goldacre, 1952; Loewy, 1949, 1950, 1952; Frey-Wyssling, 1949, 1953, 1955). The rhythmic deformations of contractile protein networks in the plasmodium are not synchronous nor perfectly random in their phases, but may be properly distributed along the canals in the plasmodium. In other words, if waves of contraction and expansion of submicroscopic networks of contractile proteins move along in one direction, protoplasmic streaming in this direction can be realized. This will be discussed in some detail in the next paper (Kishimoto, 1958). The flows from some of these canals in the plasmodium are supposed to pour into the connecting strand in our experiment, resulting in a vigorous streaming through it.

Generally in the process of molecular deformation (*i.e.*, folding and unfolding, or contraction and expansion) of contractile proteins or polyelectrolyte gels, change in ionic concentration occurs. Such a process will bring about a rhythmic change of local electric potential of the slime mold. These potential rhythms are distributed throughout the plasmodium and each contributes as a whole to a potential rhythm of the plasmodium.

With the image of the mechanism of protoplasmic streaming of the slime mold introduced here, we can explain, at least qualitatively, some aspects of its electric potential rhythm.

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