THE DAILY LIFE OF AMŒBA PROTEUS

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The purpose of the investigation described in this paper was to determine the events in the daily life of *Amœba proteus*—its periods of rest and activity, its reactions to foods and other natural stimuli in its surroundings, how it lives and what it does.

The investigation was made by watching continuously for six days and five nights several amœbas and keeping careful records of their activities. One amœba was followed with special care, while several others under various conditions as to food were also observed continuously during this period, and daily for several weeks following. The amœbas were kept under as nearly natural conditions as possible, and there was every indication that their lives under the microscope were normal. The investigation was made in the Biological Laboratory of Clark University during the winter of 1905-6, under the direction of Professor Hodge. The continuous observations were maintained in relays by Drs. Hodge, Dellinger and the writer.

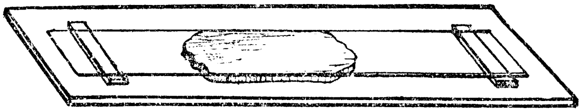


FIG 1.

The amœbas were kept in a special slide, consisting of a long cover-glass resting on two glass strips cut from an ordinary slide. A drop of water containing the amœba, when inserted between the slide and the cover-glass, clung to both by capillary attraction and made a perfect cell, open to the air, admitting freely of the insertion of pipette, needle, or additional water or food. The cells, when not under observation, were placed in a covered glass jar to prevent evaporation. The amœbas in one cell in this way were kept under daily observation during a period of eight weeks.

The question of the behavior of amœba is not a new one. The movements of no one animal have been studied so repeat-

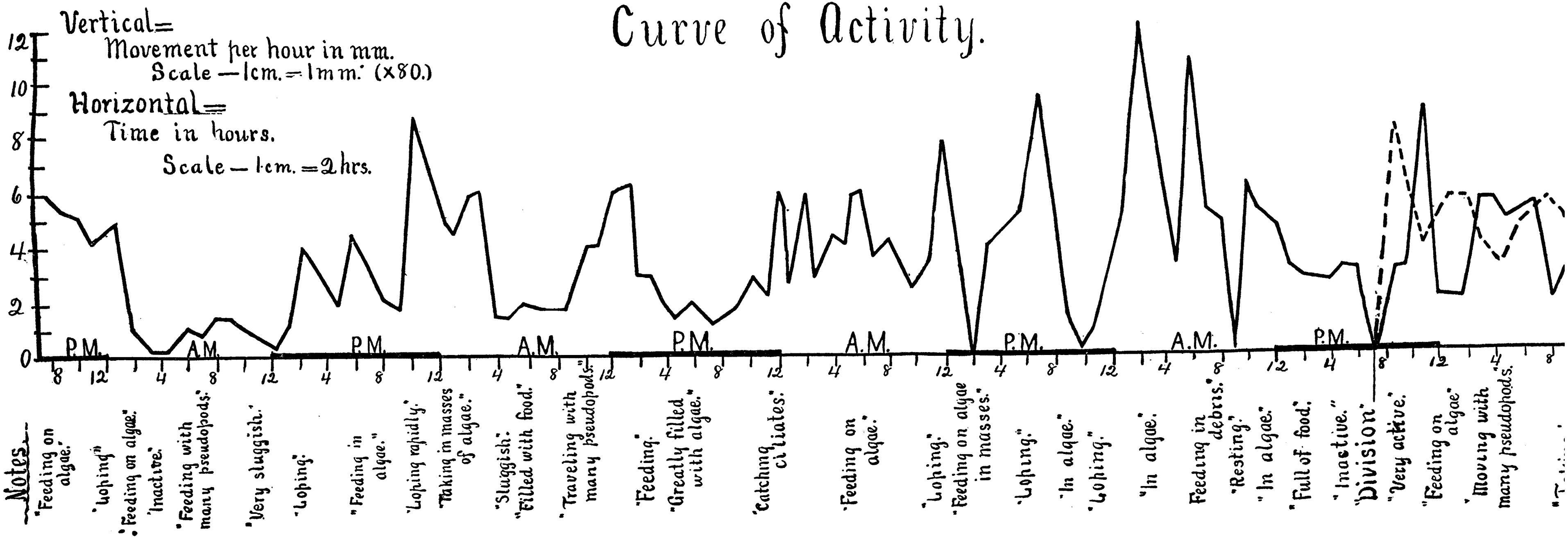
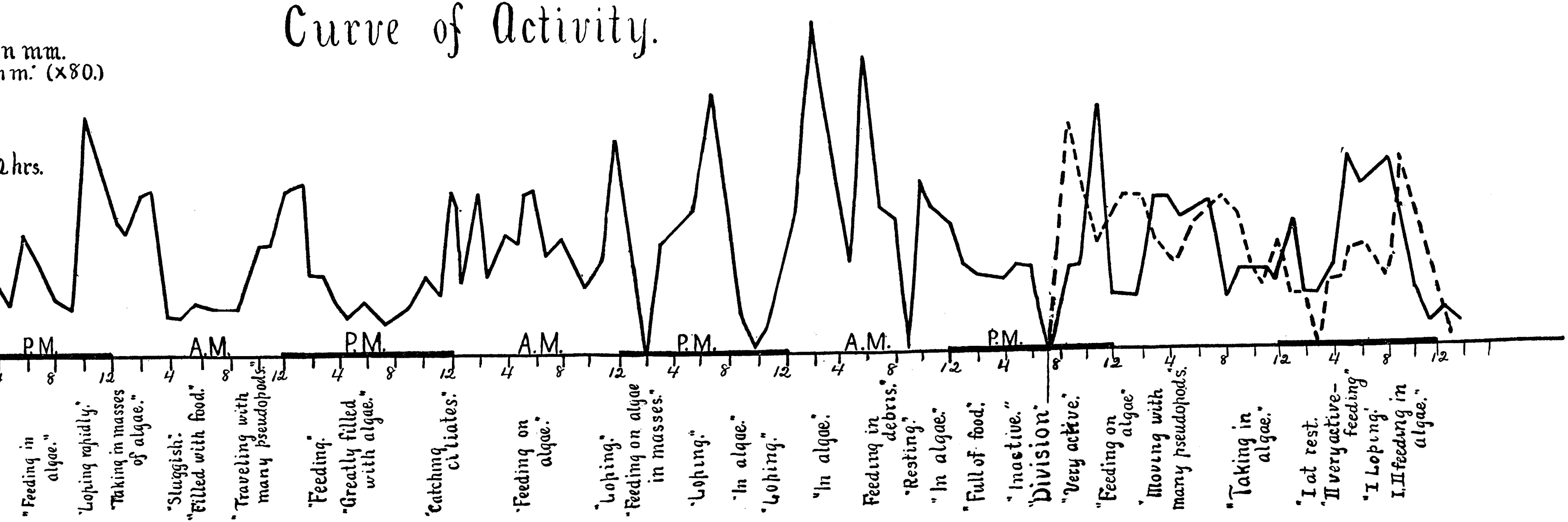


FIG. 2.

By "loping" is meant alternate lengthening and shortening of the body as a whole without pseudopods.



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edly, so carefully, for so many years, and so frequently referred to as those of the amœba. College courses in biology, zoölogy, and some important branches of these sciences find it convenient to start with the amœba. The amœba is basal in biological and physiological theory as a key to the functions and general activities of protoplasm. "Amœbic" and "amœboid" are common terms in scientific literature. The amœba figures in discussions of immortality, heredity, and death. Further, because of the amœbe's apparently simple structure, attempts to produce life artificially have been largely in imitation of the amœba, and it has been connected with "primordial slime" as probably the first animal to be developed. All these indicate how important, even fundamental, is the life history of this animal for the sciences concerned with the theory and development of life.

Throughout the animal series in general the activities of *search for food* and the *rhythm of work and rest* are basal. Success in search determines the life of the individual and of the species to a very large extent. Search is illustrated in all degrees in the life series from the gradual explorations of the root tips of plants to the complex activities of man. The rhythm of work and rest is a necessity imposed by the nature of protoplasm. It is illustrated in all degrees of rest from mere cessation of activity to profound slumber and hibernation. This rhythm is closely connected with effort in search and the attainment of food. For the higher animals this rhythm is necessary for life, but it has been doubted whether it is necessary or is exhibited in the life of the protozoa. The answer to this question is very important in its physiological bearings.

The investigation here briefly summarized showed very definitely that *amœba proteus* does have periods of activity and of rest as reactions connected with search for, and attainment of food. These periods apparently have nothing to do with light or darkness, day or night. The amœba moves actively feeding until well filled with food when it remains quiescent for a time.

These general facts are shown by the curve opposite, which represents the measured activity of an amœba during four days and nights, up to division, and the activity of the parts for two days and nights thereafter.

The curve shows the amount of movement. During the observations the movements of the amœba were measured by the micrometer gauge. At the same time careful notes were taken of the activities of the amœba. Quotations from these notes are placed below the curve and serve largely to explain it. Together they show fairly clearly that a period of activity and feeding was followed by a period of cessation of general movement, and often of apparently complete rest, that the greatest activity was immediately following a period of rest, that the degree and length of rest were in proportion to the degree and length of activity, that the rhythm of activity and rest was most pronounced during the twenty-four hours before division, that during the twelve hours before division the amœba was less active, and divided when at rest, that the parts immediately after division were very active and maintained a high level of activity during the two days in which they were observed.

The greater activity of the parts after division is also definitely shown in the following cuts which represent the actual paths travelled by, first, the amœba before division, and, second, by the parts after division.

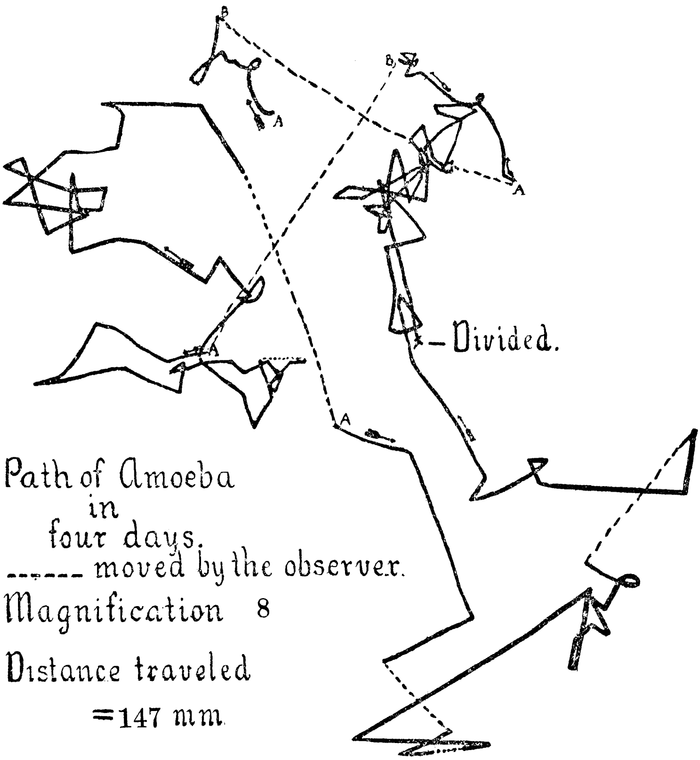


FIG. 3.

This diagram (Fig. 3) shows that the amœba travelled 147 millimeters during the ninety-six hours preceding division, while the following diagram shows that after division one part travelled 45 mm., and the other 52 mm. in thirty-one hours.

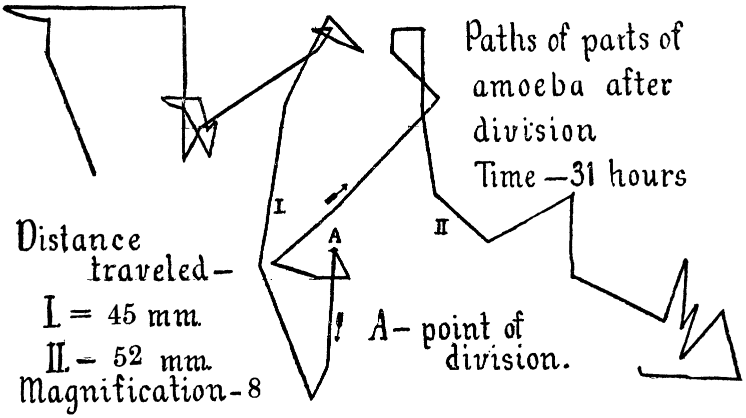


FIG. 4.

The amount of activity is also related to the amount and the kind of food. The amœba observed above was feeding mainly on unicellular algæ and was disturbed only occasionally by ciliates. When feeding on algæ scattered in the field, the amœba was more active than when feeding in a field of abundant supply. In either case it was necessary, however, for the amœba to move about to get its food.

On the other hand, amœbas, which were feeding on ciliates, when these were numerous, moved comparatively little and at long intervals of time, but when the ciliates were less numerous the amœbas were again more active.

The following curves (Fig. 5) show the activities of two amœbas feeding on ciliates. They were observed continuously for sixty-six hours. In the first place it will be observed that the activity was greatest during the first part of this period and became less and less. This was apparently the result of an increase in the number of ciliates in the cells. The necessity for action became less and less. A comparison of this curve with the curve of activity above (Fig. 2), which is on the same scale, shows strikingly this relation of movement to the food. The same fact is also even more strongly illustrated by a comparison of the paths of the amœbas in the two cases.

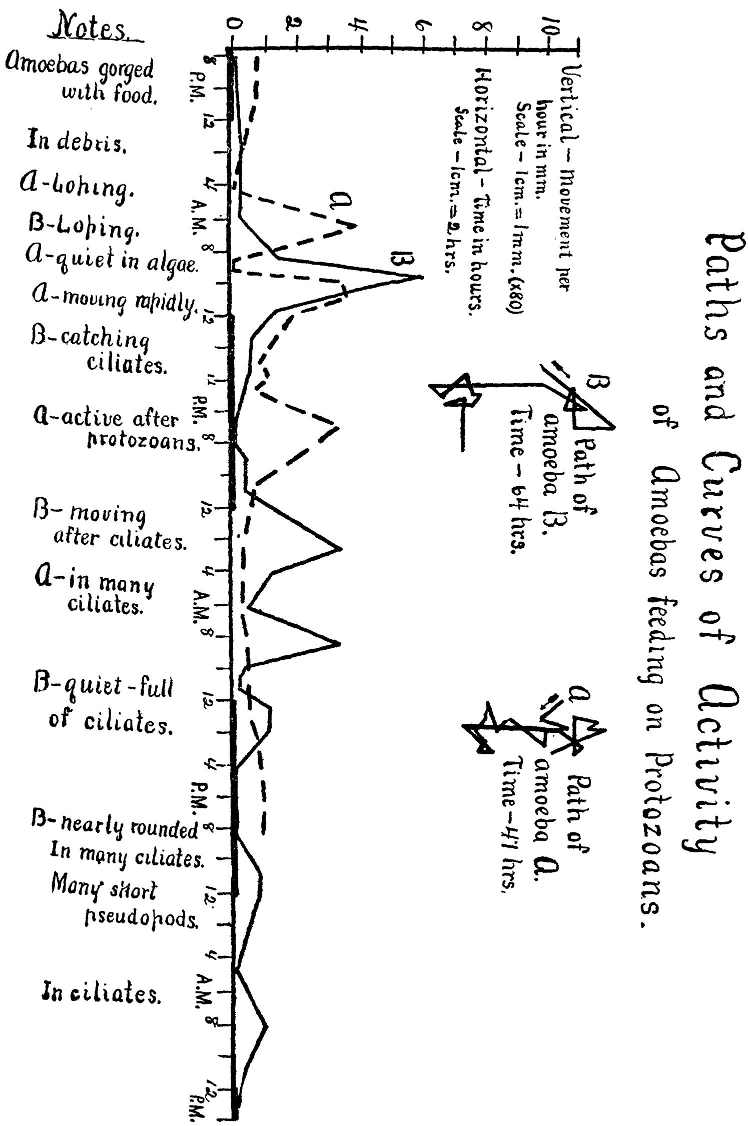


FIG. 5.

A similar investigation made in the Biological Laboratory of Clark University on *Vorticella* seemed to show that this animal worked continuously, without any periods of rest. From this, others (not the investigators) have concluded that proto-

PLATE I. An amœba feeding on algæ.

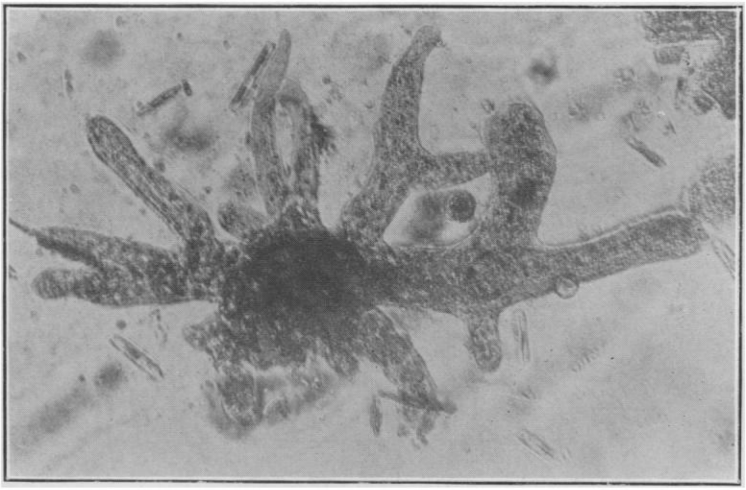


PLATE II. An amœba feeding on protozoa.

zoans never rest and that the rhythm of work and rest was only gradually evolved with the more complex forms of life. It seems, however, that the rhythm is here well developed in this lowest form of animal life, Activity, feeding, rest; activity, feeding, rest, is the story of the above curve. Activity, or the performing of work, requires energy which the protoplasm must supply. The period of rest appears to be simply the result of organic satisfaction, or a period of recuperation. It suggests the lowest form of sleep; for this tendency to rest, to sleep, as a food reaction is illustrated by the higher animals. In this respect this lowest form of life does not differ essentially from the higher forms.

The reactions of the amœba to, and its search for, food also brought out many important facts in its life history.

In the absence of food the amœba often moved by "lopes", that is, by lengthening and shortening its body as a whole without extra pseudopods, and moving rapidly forward.

Amœbas feeding habitually on algæ assumed a palmate form, moving forward with many pseudopods, similar to the form pictured in Plate I.

An amœba feeding on ciliates responds to a touch by a ciliate by sending out pseudopods at the point touched and following up the ciliate. The pseudopods are sent out on both sides of the ciliate until the latter is nearly enclosed and then rapidly connected, forming a chamber, in which the ciliate may finally be engulfed. The ciliate may, however, escape, leaving the chamber open. Some observers, seeing the "pursuit" at this stage, have concluded that the amœba formed the chamber before the partial enclosure of the ciliate.

In the presence of a large number of ciliates the amœba moves about but little. It sends out many pseudopods forming pockets, apparently in readiness for them, and often succeeds in catching them with remarkable rapidity. Our observations seem to indicate that this reaction is characteristic only of amœbas that have for several days been feeding on ciliates.

The adjacent photograph (Plate II) shows an amœba catching protozoa. The following series of camera lucida drawings of an amœba moving into a field containing ciliates shows the forms characteristic in a number of captures and also the peculiar pocketed outline and hooked pseudopods which seemed to be characteristic of forms feeding habitually on ciliates. See Fig. 6.

The amœba often follows a paramœcium or a ciliate until it is caught or lost. This "pursuit" may continue for twenty minutes or more as is indicated by the drawings of an actual instance, Fig. 7. The drawings show the touch by the paramœcium, the "pursuit," the partial capture and formation

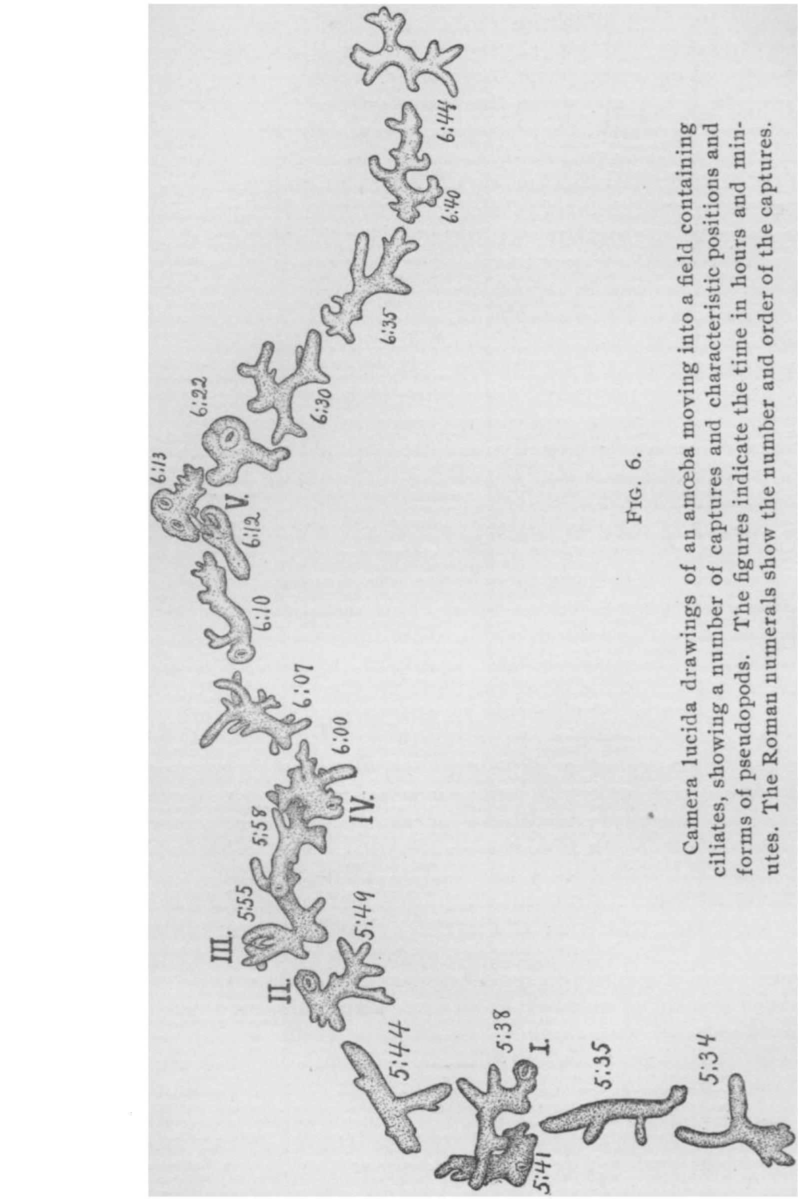


FIG. 6.

Camera lucida drawings of an amœba moving into a field containing ciliates, showing a number of captures and characteristic positions and forms of pseudopods. The figures indicate the time in hours and minutes. The Roman numerals show the number and order of the captures.

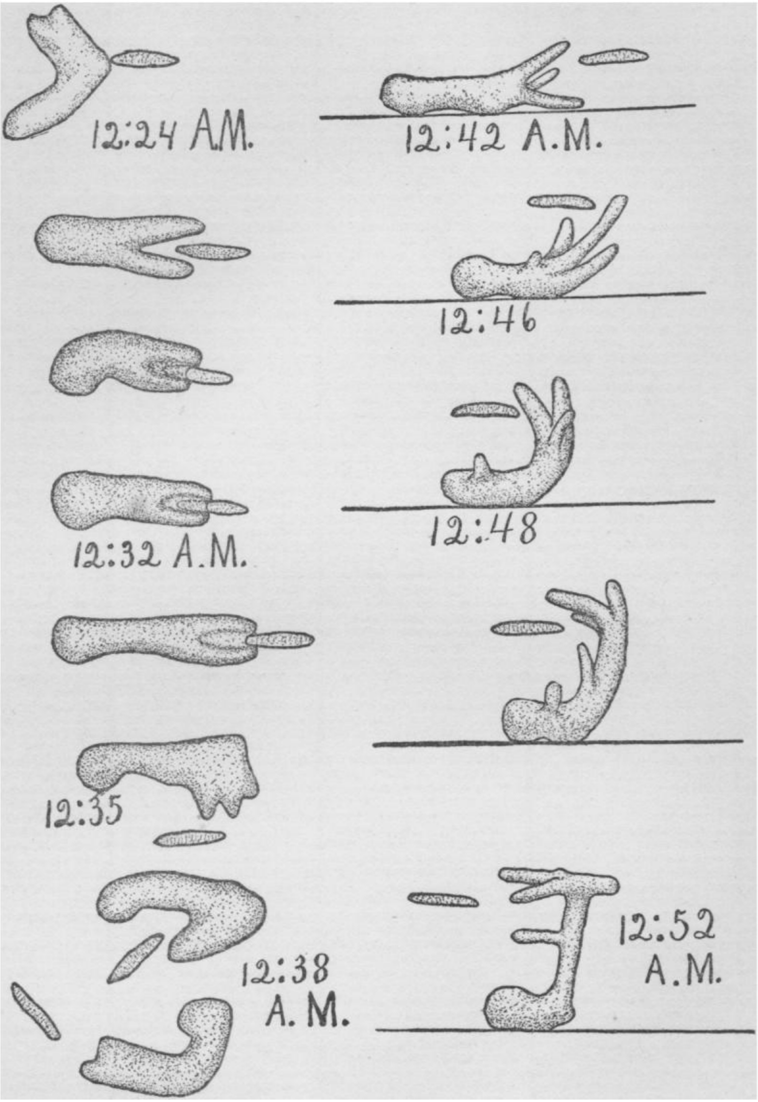


FIG. 7. The "Pursuit".

of the chamber, the escape of the paramœcium, the further "pursuit" at a higher level, and the final escape.

When in "pursuit" in this way the amœba does not generally respond to other stimuli, especially if close upon its prey.

It seems able to detect a paramœcium at some distance, and will continue the "pursuit" some time after the paramœcium has gone from the field. The intensely interesting sight of an amœba after numerous trials gradually sliding its pseudopods around a feeding paramœcium, throwing a cover over it, closing the pseudopods, and gradually squeezing the struggling victim down to a rounded mass can hardly be described without using anthropomorphic terms. It requires a number of adaptations and considerable skill, which our observations seem to indicate are acquired by the "method of trial and error." The capture is seen to be difficult when we compare the reaction times of the two animals. That of the paramœcium is too short to be measured without special chronometric apparatus, while that of the amœba is about one and one-fourth seconds.

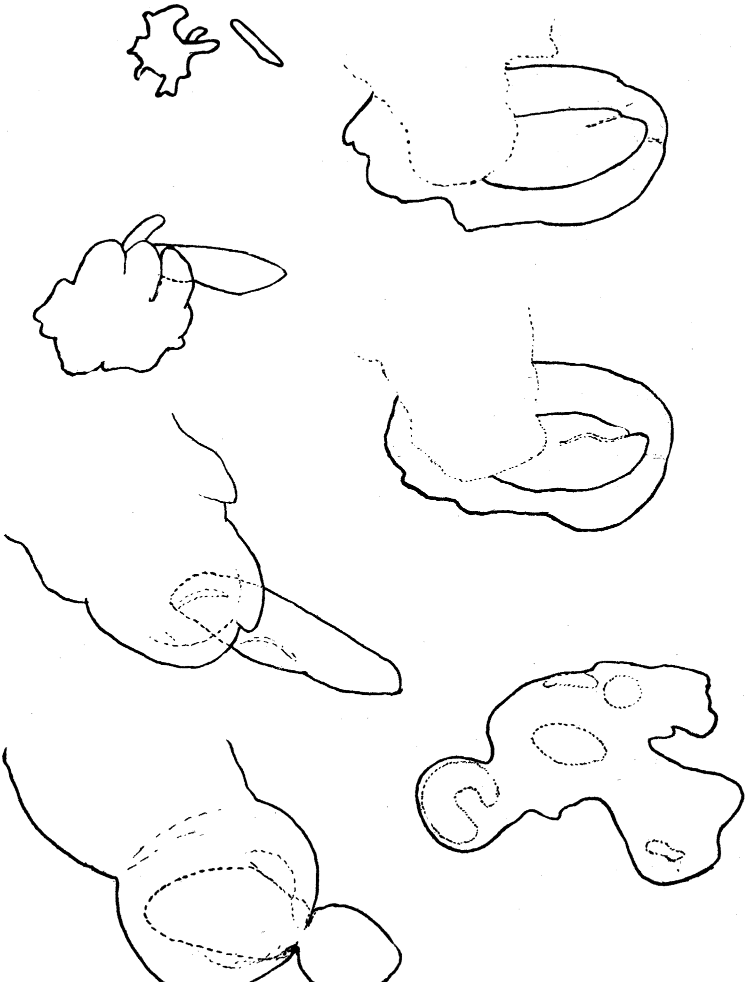
The stages and adaptations of "pursuit" are well shown in the photographs by Dr. Dellinger, Plate III. They show the first stage of "pursuit," the gradual enclosure, the formation of the chamber, the tension or squeezing effect, the enclosure, and finally an amœba containing a recently captured paramœcium and the partially digested remains of four or five others.

This slow reaction time of the amœba must be considered when describing its choice of food. It may be seen partially to enclose dead cells or ciliates and then withdraw, for the reaction-choice apparently cannot take place until some time after contact.

The amœba shows distinct food preferences: with diatoms and unicellular algæ, it takes algæ, but when feeding on algæ it will leave them to "pursue" ciliates. In the presence of large paramœcia, some amœbas leave algæ and ciliates to catch these larger forms. Amœba eats nothing dead. This was observed in the case of dead diatoms and algæ cells, of paramœcia dead from natural causes, and of paramœcia which had been artificially killed. Amœbas apparently do not eat their own species, but were seen to eat amœbas of other species.

When the food is changed as a whole, some observations seem to indicate that many amœbas required several days to make the adjustment, especially if this adjustment means new adaptations and movements, as in passing from feeding on algæ to feeding on paramœcia. But all are not alike; some amœbas seemed able easily to adapt themselves, while others were unsuccessful. The advance in complexity of the one stage over the other is very great.

An amœba suddenly placed in the midst of a large number of paramœcia, which bump it and knock it about, usually makes no response to the separate stimuli, but seems "confused." Later, some amœbas in these circumstances, put out pseudopods and may "pursue" a single paramœcium without



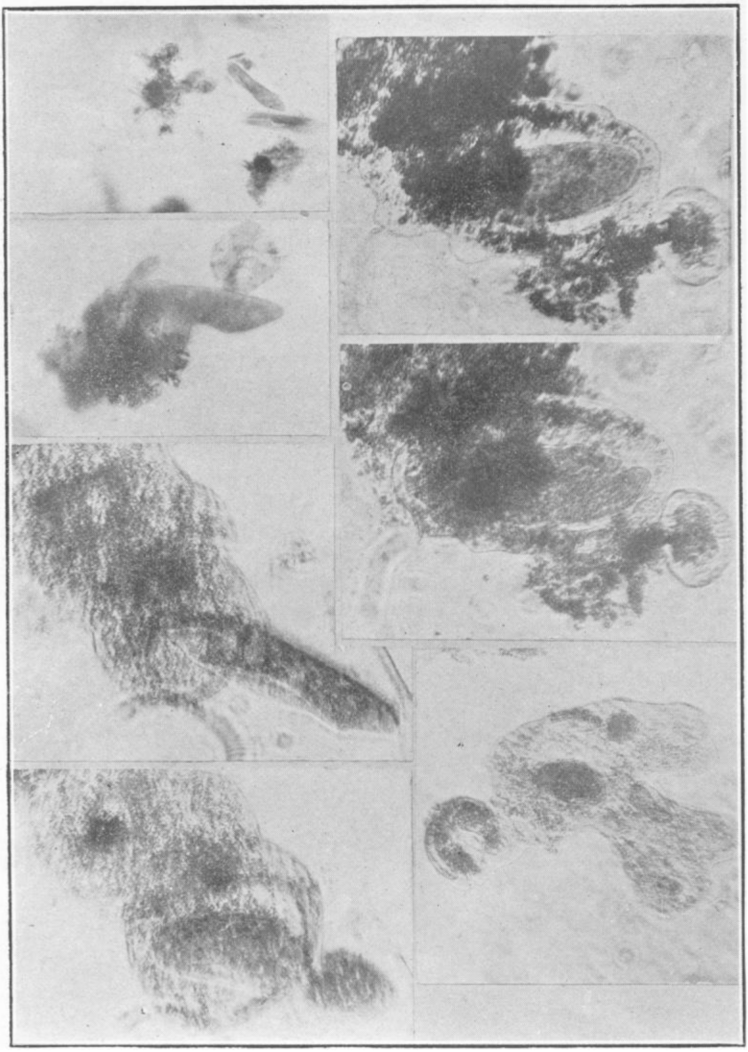


PLATE III.

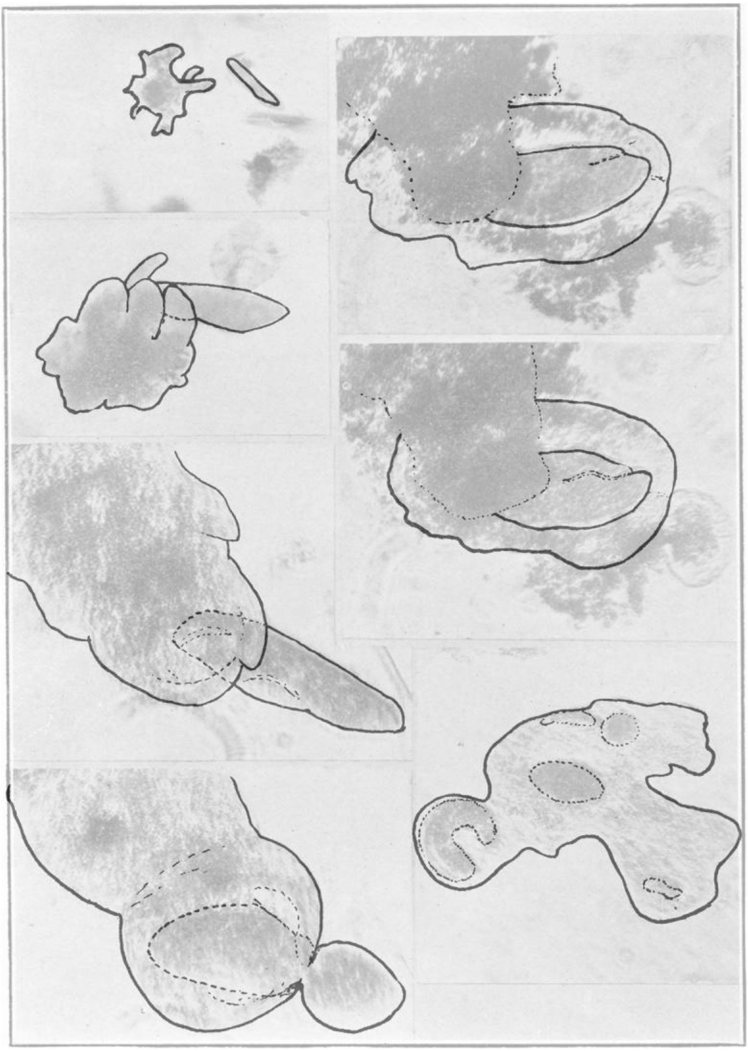


PLATE III.

much regard to touches from the others; while some appear never to get their equilibrium, but move off or take the spherical form.

A number of minor observations should be noted. The action of the contractile vacuole was carefully observed. It was found that the rate of its pulsation varies greatly, but was slowest in nearly rounded and sluggish forms, and more rapid in actively moving forms, that it empties through the ectosarc with a distinct mouth, that some fluid is discharged, that the vacuole usually, if not always, reappears at the same spot. The evacuation of particles was also frequently seen taking place from a food vacuole, the particles being expelled by contraction of the vacuole.

Although amœba were often found in contact, no trace of conjugation was observed. On the other hand, they were frequently observed to avoid each other.

From the facts observed it would seem that

1. The *amœba proteus* in common with higher animals has distinct periods of work and rest, depending for degree and duration upon the nature and abundance of food upon which the animal is habitually feeding.

2. That the *amœba proteus* has food preferences and in general the power of adapting itself to changes in food conditions. This power of adaptation and of choice is perhaps the result of a learning process based upon the "method of trial and error."

3. That the *amœba proteus* is capable of a sort of "pursuit" with the various adaptations which this involves.

The study seems to show that amœba can no longer be considered as a bit of but slightly differentiated protoplasm, but must take its place in the true animal series with the rudiments at least of true animal behavior.

LITERATURE

Recent bibliographies on the reactions and behavior of the Protozoa are so complete and so readily accessible that no attempt is made to repeat them in this brief communication. Instead the reader is respectfully referred to:

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