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STUDIES ON REACTIONS TO STIMULI IN UNICELLULAR ORGANISMS.

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III. Reactions to Localized Stimuli in Spirostomum and Stentor.

In the second of these studies (*American Journal of Physiology*, May, 1899) the writer has given an account of the mechanism of the reactions of Paramecium that involves an entirely different conception of the nature of these activities from that which has been generally assumed. It was shown that this protozoan has but one motor reaction in response to the most varied stimuli, and that it reacts without any relation whatever to the position of the stimulating agent, so that it cannot be said to be attracted or repelled by any agency or condition — its reaction being strictly comparable in all essentials to that of an isolated muscle. The importance of this, in case it should turn out to be the general method of reaction for unicellular organisms, is obvious, involving, as it does, the rejection of almost all hitherto received theories of the mechanism of reactions; the question, therefore, immediately arose as to whether this method of reaction was to be extended to other Protozoa. The following study of the reactions of Spirostomum and Stentor is presented as a contribution toward answering this question.

The minute size of Paramecium brought with it the great disadvantage that it was not possible under experimental conditions to apply localized stimuli to definite parts of the body, so that recourse was necessary to observation of chance contacts of sources of stimuli with one or another part of the body; an unsatisfactory method, and one requiring much time and patience. This difficulty is obviated in *Spirostomum ambiguum* and *Stentor polymorphus*, which are both so large that there is no difficulty in applying stimuli to any desired region on the surface of the body. The simplest means of doing this is to touch any point on the surface of the body with a proper instrument, thus giving the animal a sharply localized mechanical stimulus. Other methods are given in the following account of observations.

Spirostomum ambiguum (Fig. 1).

Spirostomum ambiguum is one of the largest of unicellular animals, reaching a length of two or three millimeters. The average length of those on which the following observations were made was about one and one-half millimeters. In form Spirostomum is a long, slender cylinder of nearly equal diameter throughout, but slightly smaller at the ends. The mouth lies behind the middle of the body, and from this a band of large cilia (the adoral zone) runs to the anterior end of the body. The large contractile vacuole lies at the posterior end, and from this a canal runs almost the entire length of the body near its aboral side, or curving a little onto the right side. The adoral zone and this canal form important landmarks for determining directive relations in studying the movements of the animals. The posterior end is truncate, while the anterior end is rounded and shows a difference in its contour on the two sides of the animal. The tip is curved slightly toward the side on which the mouth is situated (the oral side), so that on the opposite or aboral side the contour is a long convex curve, while on the oral side there is almost an angle. These facts are best appreciated in the figure; while not prominent, they are visible, and are of the greatest importance for orientation while studying the movements of the animal. The difference in the two contours of the anterior end possibly does not correspond precisely to the distinction between the oral and aboral sides, as determined by the position of the mouth; the exact relation of parts is very difficult to determine on account of the continual twisting movements of the animal. But the difference in contours in any case marks very nearly the oral and aboral sides, so that when the aboral side is spoken of in the following account it signifies that side of the anterior end in which the curve is longest, while the oral side is that which presents the shortest curve (see Fig. 1). The entire surface of the animal is covered with cilia, arranged in somewhat oblique longitudinal rows.

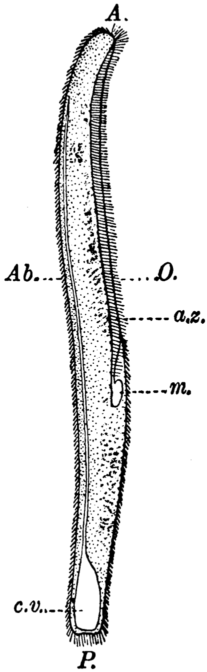

FIG. 1. — *Spirostomum ambiguum*, right side. *A*, anterior end; *P*, posterior end; *O*, oral side; *Ab*, aboral side; *a.z.*, adoral zone; *m*, mouth; *c.v.*, contractile vacuole.

The unstimulated Spirostomum swims forward by means of the backward stroke of its cilia; at the same time it may revolve on its long axis. This revolution is usually from right to left. The body (as shown in Fig. 1) is not quite straight, but a little in front of the middle is slightly bent, so that the anterior part, as the body revolves, describes the surface of a cone. Owing to the animal's continual movement and its power of twisting into a spiral and of bending sharply, taken in connection with the only slight differentiation on the surface of the cylindrical body, the orientation of the body in relation to the direction of movement is very difficult to determine. But by keeping the attention fixed upon the form of the anterior end, as described above, it is possible under favorable conditions to observe that the aboral side of the anterior end is always on the outside of the cone, the oral side looking within. As the animal moves forward in connection with this revolving motion, the path of course becomes a spiral; it agrees exactly with the path of Paramecium, in that the aboral side always looks toward the outer side of the spiral. At times the animal swims some distance without revolving on its long axis; at such times the path is not a spiral.

We will now proceed to a systematic examination of the changes in motion due to stimuli of different sorts and applied at different points on the animal's body.

A. *Mechanical Stimuli.*

The method of study consisted in touching with a capillary glass rod, of less diameter than the animal's body, different points on the surface of the animal, and noting the reactions caused. This procedure presents no difficulties.

1. *Stimulus at Anterior End.* — If the animal is touched at the anterior end with the tip of the glass rod, it immediately contracts strongly, becoming short and thick, and the zones of cilia forming spirals surrounding the body, in the manner well known. (See the figure given by Bütschli in *The Protozoa of Bronn's Klassen und Ordnungen des Thierreichs*, Taf. LXVII, Fig. 2 *b*.) At the moment of contraction it darts backward a little. It then gradually extends, continuing to swim backward. As it swims backward it revolves on its long axis, in all cases observed, from right to left, in the same direction as when swimming forward. Next it begins to turn its anterior half to one side, usually at the same time beginning to swim forward. Like Paramecium, it always turns toward the aboral side of the anterior end. It usually revolves at the same time, so as to describe a very wide spiral, with the aboral side on the outside of the spiral, finally straightening out and swimming forward in the direction indicated by the position of the aboral side at the time it straightens. Briefly, the animal when stimulated at the anterior end contracts, backs off, turns to the aboral side, and swims forward on a path which lies at an angle to the path on which it was previously swimming. In the case of a very slight stimulus the contraction may be omitted, the rest of the reaction being given as usual, ex-

cept that the animal swims only a short distance backward before turning.

2. *Stimulus at Posterior End.*—If now the animal is touched at the posterior end, exactly the same reaction is produced. It contracts, then swims backward,—therefore toward the point of stimulus (whereas in the other case it swam away from the point of stimulus). Then it curves toward the aboral side, describing a wide spiral, and finally swims forward in the direction of the aboral side, exactly as described above. It makes no difference to the reaction which way the animal is swimming when stimulated: if swimming forward, the direction is changed; if swimming backward when touched at the posterior end, it continues to swim backward after contracting.

The posterior end is slightly less sensitive than the anterior, so that a very weak stimulus at the posterior end may cause no reaction at all. No matter where stimulated there are rare cases in which the animal when stimulated merely contracts (always darting back a little at the moment of contraction), then stops for a time, then resumes a forward motion. Out of one hundred cases stimulated at the anterior end, ninety-six reacted in the typical manner, while four gave the incomplete reaction just mentioned. Out of one hundred cases stimulated at the posterior end, ninety-two gave the typical reaction, while eight reacted incompletely. This difference in the number giving the typical reaction is probably a mere statistical variation, which would disappear with larger numbers; if any significance is to be attached to it, it is merely that already noted—that the posterior end is slightly less sensitive than the anterior.

The reaction is thus exactly the same whether the stimulus occurs at the anterior or the posterior end.

3. *Stimulus at One Side.*—When the animal is touched anywhere on the surface of the body between the two ends, the same reaction is given as in the two foregoing cases; the animal contracts, swims backward, curves toward the aboral side, and swims forward toward that side. The final direction in which it swims bears no relation to the position of the side on which the stimulus was given.

4. *Stimulus Unlocalized.*—An unlocalized mechanical stimu-

lus can be given by jarring the dish or slide containing the animals. They contract, swim backward, turn toward the aboral side, and swim forward, exactly as in the other cases.

Thus the reaction given by Spirostomum to a mechanical stimulus is identically the same, whatever part of the body is stimulated, or even if the stimulus is not localized at all. A diagram of the reaction of Spirostomum to a stimulus is given in Fig. 2.

5. *Repeated Stimuli.* — When the same animal is repeatedly stimulated, certain features in the reaction are especially worthy of notice. At the first stimulus the animal contracts, then

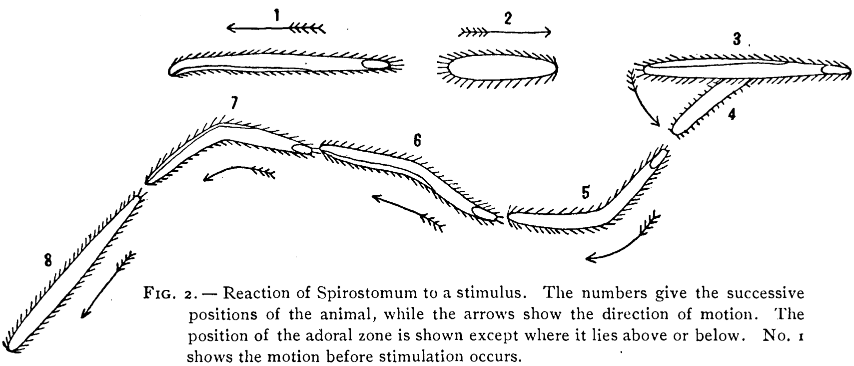

FIG. 2. — Reaction of Spirostomum to a stimulus. The numbers give the successive positions of the animal, while the arrows show the direction of motion. The position of the adoral zone is shown except where it lies above or below. No. 1 shows the motion before stimulation occurs.

swims backward. Now if, after recovering from the contraction, but while still swimming backward, it is again stimulated, it again contracts and continues to swim backward. On a third stimulation, while still swimming backward, it usually *reverses* its course and swims forward. A reversal of the direction of motion now usually occurs at each new stimulus up to four or five. This reversal at each new stimulus may easily give the impression that the animal is swimming each time away from the source of stimulation, and hence that it is reacting with relation to the localization of the stimulus; but this appearance is due merely to a psychological peculiarity of the experimenter. It is natural for the experimenter to touch the animal at the end toward which it is moving — to "head it off" as it were. On the third trial he will, as above stated, usually succeed in getting it to reverse its motion and swim in the opposite direction. He then "heads it off" again by touching the other end toward which it is now swimming, with the result that it reverses again. This alternation on the part of experimenter and infusorian may continue for a number of times, giving the impression that the animal is clearly reacting with reference to the position of the source of stimulus, fleeing from it in each case. But this alternation is really an independent phenomenon in each of the two organisms concerned in the experiment, as is proved by the following. If the experimenter continues to stimulate the animal at the same end, regardless of the direction in which it is moving, the animal's direction of motion will alternate as before. Thus, after the second stimulation, while the Spirostomum is swimming backward, if stimulated at the anterior end, it will now swim forward or toward the source of stimulus; if stimulated again at the anterior end, it will reverse and swim backward; again, and it swims forward once more. In these cases, as in the others, therefore, the direction of motion has no relation to the localization of the stimulus.

If the stimulations are continued after five or six times, the animal will continue to swim violently in one direction or the other, without regard to the repetition of the stimulus or its localization. It is thus possible to stimulate the animal repeatedly at its posterior end while it is swimming violently to the rear, and thus toward the source of stimulus; in other cases it swims as violently away from the stimulus. In no case does the position of the stimulus have any effect on the direction of motion.

B. *Chemical Stimuli.*

It is easy to localize the action of chemical stimuli in the following manner. A capillary glass rod is coated with paraffin. A crystal of NaCl or other salt is then attached to the rod by means of the paraffin coating, and can then be held near to any part of the animal's body.

1. *Stimulus at Anterior End.* — The crystal of NaCl is held close to the anterior end of the Spirostomum, but without touching it, so that only the diffusing salt in solution comes in contact with the animal. The Spirostomum contracts, swims

backward (away from the source of stimulus), turns toward the aboral side, and swims forward, exactly as in the case of a mechanical stimulus.

2. *Stimulus at Posterior End.* — The crystal of salt is held close to the posterior end. The animal contracts and swims backward — therefore *toward* the source of stimulus. It thus either strikes the crystal of NaCl or passes through the densest part of the solution; then continues backward some distance, finally turning toward the aboral side and swimming forward.

3. *Stimulus at the Side.* — The animal reacts as in the two preceding cases, the direction of motion having no relation to the position of the stimulus.

4. *Stimulus Unlocalized.* — The Spirostoma are dropped directly into 2 per cent NaCl. They contract, swim backward, turn about irregularly, and soon die.

The following experiment, giving results in almost all the above categories, is particularly striking. A number of Spirostoma are placed on a slide in a considerable quantity of water. Then a few crystals of NaCl are placed in the center, the cover-glass quickly supplied, and the reactions of the animals noted. All those in the immediate neighborhood of the NaCl soon contract and swim backward, as the flood of salt solution diffusing from the crystals comes against them. The Spirostoma are scattered, with axes oriented in no special direction, therefore some lie with anterior ends directed toward the mass of salt, so that this end first comes in contact with the salt solution; others with posterior end thus directed; others with long axis oblique to the direction of the mass of salt. All contract and swim backward, whatever part of the body is first met by the diffusing solution of NaCl. Those with anterior ends directed toward the mass, swimming backward, of course move directly away from the salt. Those with posterior end toward the salt, likewise swimming backward, pass directly into the densest part of the solution of NaCl, and are quickly plasmolyzed and killed. Those with long axis oblique to the direction of the NaCl also swim backward, some thus approaching more or less obliquely the solution of NaCl; these do not turn, but swim straight on, crossing the area and coming out on the other side, unless plasmolyzed and killed during the passage.

It is evident that the Spirostoma are neither attracted nor repelled by the NaCl; it merely sets in operation their one reaction, and this takes them into danger or safety as chance may direct. Under normal conditions, of course, the anterior end will usually be directed toward the stimulating agent, since the animal generally swims forward, and masses of dangerous chemicals are not often dropped suddenly into the midst of a group of the Infusoria; hence the device of swimming backward usually saves the animal. The following curious experiment shows how possibly a combination of circumstances might arise even under normal conditions such that the reaction would result in the destruction of the animal. A small mass of NaCl was slowly dissolving in the center of the slide. A Spirostomum was swimming forward directly away from the diffusing salt, not being in the region of its influence at all. Its posterior end was thus pointed toward the salt, but as it was swimming away it was in no danger. Now a slight jar was given to the preparation — such as might easily occur in nature. Thereupon the Spirostomum reacted in the usual manner, by contracting and swimming backward. It thus swam toward the NaCl, until finally its posterior end came in contact with the advancing flood of salt solution. Thereupon the customary reaction was again induced still more powerfully; the animal contracted and swam still more swiftly backward; thus entering the salt solution, it was plasmolyzed and killed.

When a Spirostomum swimming forward comes in contact with a diffusing chemical, it contracts, darts backward, then swings its anterior end about, finally turning toward the aboral side and swimming straight forward — so long as this does not take it again into the region of the stimulating agent. If it does, the reaction is repeated until by the laws of chance the Spirostomum is directed into a region which does not cause stimulation. If the stimulus with which the anterior end comes in contact is very weak, the animal may omit the contraction and move a little backward without contracting; then the anterior end is swung about in a circle (the aboral side, of course, toward the outside of the circle), while the animal starts forward. So long as the anterior end is thus carried into a medium which causes the weak stimulus, the forward movement is at once checked and the animal jerks backward again; as soon, however, as the anterior end in its circling comes into a direction such that swimming forward does not carry the animal into a region causing the reaction, the animal continues to swim straight forward. All these facts find a precise parallel in the reactions of Paramecium.

When the Spirostomum is swimming backward, the course is never changed by the circling about of the posterior end and the turning in one way or another, as it is when the anterior end is directed forward; the posterior end seems to have no power of initiating a turning movement. In this connection the reactions of the separate parts of a Spirostomum, cut into two or more pieces, is of interest.

C. *Reactions of Separated Parts.*

There is no difficulty in cutting Spirostomum with scissors or scalpel transversely into short pieces. Any piece with which the anterior end remains in connection, though it be but one-tenth of the entire animal, reacts in essentially the same way as the entire organism — by contracting, swimming backward, turning and swimming forward. Its motion, perhaps, differs a little in degree from that of the entire animal in the fact that turning is more frequent and pronounced, the piece at times swimming in a small circle. The direction of turning is, as in the uninjured specimen, toward the aboral side. Any piece from which the anterior end is separated, while the posterior end is uninjured, reacts as follows. When stimulated, it contracts and swims backward, *does not turn*, but soon swims forward. It swims but a short distance forward, then starts backward again; after going in this direction once or twice its own length, it swims forward about the same distance; then again backward. It continues thus to oscillate back and forth indefinitely. When the anterior end is removed, therefore, the motion takes the form of a rhythmical back and forth movement. This is true when the posterior piece comprises as much as nine-tenths of the entire animal.

It seems, therefore, that the power of initiating a turn, and the power of continuing a course once begun, are localized in some way in the anterior end.

Stentor polymorphus (Fig. 3).

Stentor polymorphus is smaller than *Spirostomum ambiguum*, but is still of sufficient size to make the application of localized stimuli a matter of no difficulty. It is a trumpet-shaped animal, exceedingly changeable in exact form and proportions. Fig. 3 shows a usual form of the animal when swimming freely; when anchored by its base the form is more extended and slender. The surface of the animal is covered with cilia in longitudinal rows, while the broad anterior end, known as the peristome, is surrounded by a circle of larger cilia forming the adoral zone. At one side of the disk is a funnel-like depression which leads into the mouth. That surface of the body nearest to which the mouth lies may be called the oral surface; the opposite one, the aboral surface. Considering the oral as equivalent to ventral surface, we may define right and left sides as follows: When the oral surface is below, and the anterior end is away from the observer, the right and left sides of the animal correspond to the observer's right and

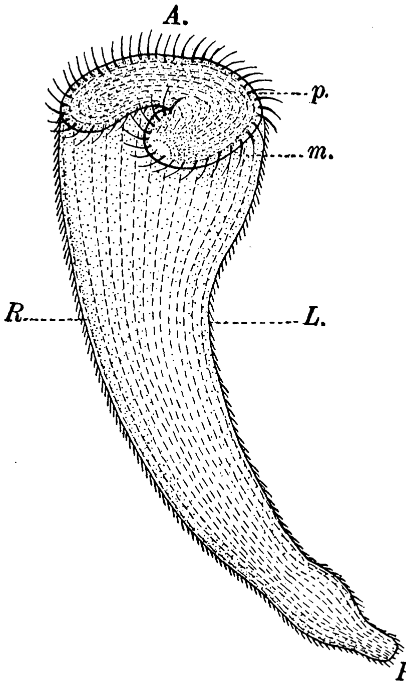

Fig. 3. — *Stentor polymorphus*, partially contracted free-swimming individual, oral surface. *A*, anterior end; *P*, posterior end; *L*, left side; *R*, right side; *m*, mouth; *p*, peristome.

left. (In the figure the oral surface is above, so that right and left sides are reversed.) The body of the animal is usually curved, being bent from the direction of the anterior end toward the left side; sometimes there is near the posterior end a second short curve to the right.

Stentor polymorphus is often found attached by its posterior end; at other times it swims freely in the water. The motion in the free-swimming individuals is as follows: The animals swim slowly forward; at the same time they may or may not revolve on the long axis. The revolution when it occurs is usually, if not invariably, to the left. When the animal swims forward without revolving on its long axis, the path is usually a curved one, the animal continually swerving toward its right side. In this way the Stentors usually describe circles of greater or less radius. If they revolve as they swim forward, they continually swerve to the right also; but owing to the revolution, the right side continually changes its position, so that the path becomes a spiral one, as in Paramecium and Spirostomum. The motion of *Stentor polymorphus* is usually very slow, so that all these relations are observable without the slightest difficulty.

A. *Reactions to Mechanical Stimuli.*

The animals were stimulated in the same way as Spirostomum, by touching them at any desired point with a capillary glass rod.

1. *Stimulus at Anterior End, on Peristome.*—The animal contracts and swims backward a short distance (its own length or a little more). As it swims backward it revolves on its long axis to the left — in the same direction as when swimming forward. Then it turns on its short axis to its right and swims forward.

2. *Stimulus at Side.*—Identically the same reaction is given as when stimulated at the anterior end; the animal contracts, swims backward, turns to right, and swims forward. The turning is not with reference to the position of the source of stimulus, but is always toward the right side. Therefore, if

stimulated on the right side, the animal turns toward the side stimulated; if on the left side, it turns away from the side stimulated. Owing to the revolution on the long axis while swimming backward, the position of the right side at the time of turning on the short axis bears no definite relation to its position at the time of stimulation; so we find that the absolute direction toward which the animal turns has no constant or prevailing relation to the absolute direction from which the stimulus came.

3. *Stimulus at the Posterior End.* — The posterior end of Stentor, narrowing to a point of attachment, is very little sensitive, so that touching it with the rod of glass usually causes no reaction whatever. By giving it a smart blow, however, a reaction can be induced, and this is then identical with the reaction already described. The animal thus, of course, swims at first *toward* the source of stimulus.

4. *Stimulus not Localized.* — If the vessel containing the Stentors is jarred, they react in the same manner as to localized stimuli.

B. *Chemical Stimuli.*

Stentor gives the same reaction to chemical as to mechanical stimuli. If when swimming forward through the water it comes

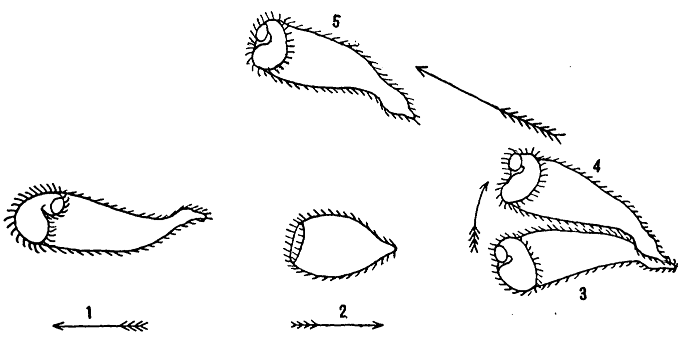

Fig. 4. — Diagram of the reaction of Stentor. The arrows show the direction of motion, while the numbers indicate the successive positions of the animal; No. 1 showing the animal before stimulation occurs.

in contact with a chemical substance sufficiently powerful to act as a stimulus, it contracts, swims backward, turns to the right, and swims forward on a new path; if this path takes it again into the stimulating region, the reaction is repeated; thus by the laws of chance the animal will in time probably be brought into a region which does not act as a stimulus. The reaction is the same whether the stimulus is localized or is a general one. The reaction is in essentials like that of Paramecium and Stentor.

The reaction of *Stentor polymorphus* is shown in Fig. 4.

Summary and Conclusions.

The reactions of Spirostomum and Stentor are similar in all essentials to those of Paramecium. To any stimulus all these animals respond by swimming backward, turning to one side, and then swimming forward. Paramecium and Spirostomum always turn toward the aboral side; Stentor, toward the right side. In Spirostomum and Stentor a contraction of the body forms an additional feature of the reaction. The reaction is not modified in any way by the position of the stimulus; the direction of motion is the same whether the source of stimulus is at the anterior end, the posterior end, the side, or if the stimulus is not localized at all. If the stimulus is at the anterior end, the animal necessarily swims away from it; if at the posterior end, it swims toward it, even when this results in the destruction of the animal. The discussion and conclusions given in my previous paper (*loc. cit.*) in regard to Paramecium are, therefore, equally applicable to Spirostomum and Stentor, and need not be repeated here.

The fact that three such dissimilar ciliates as Paramecium, Spirostomum, and Stentor agree in their reaction in all essential particulars certainly raises a presumption that the mode of reaction is of this general character throughout the ciliate Infusoria. This is especially probable in view of the fact that the revolution on the long axis and progress in a spiral course, which plays so essential a part in these reactions, and indeed seems to have the special purpose of making such a method of reaction possible, is already known to occur in the motions of almost all ciliates. Moreover, the same is known, through the researches of Nägeli, to be true of the flagellate swarm spores of plants. According to this investigator, such swarm spores swim in a spiral course, with the same side always toward the outside of the spiral — exactly as I have described for Paramecium, Spirostomum, and Stentor. Another observation of Nägeli renders it extremely probable that the mechanism of the reactions of these organisms is essentially the same as in the three ciliates named. When these flagellate swarm spores strike in their forward course against an object, they cease the forward motion for a time, but continue to turn on the long axis; then "there ensues a backward motion, with posterior end in advance, while at the same time they rotate in the opposite direction. This backward course usually lasts but a short time and becomes gradually slower; it is soon exchanged for the forward motion, which takes place, as a rule, in a somewhat different direction from the original one."[1] This description would apply without the slightest change to the reactions of Paramecium, Spirostomum, and Stentor under the same circumstances. It may be predicted with much confidence that the reactions would be found to be similar under other circumstances; that the "somewhat different direction" of the swarm spores would be found to be always toward the side which faces the outside of the spiral course, and that the same reaction would be given whatever the nature and position of the stimulus. If this is true, then the conclusions which I have drawn for Paramecium in my previous paper would apply equally to the Flagellata. Certainly until the mechanism of the reactions of these and other unicellular organisms is determined by observation, it is hardly worth while to base any conclusions on theoretical schemes of the character usually given for such reactions. Theories of the reactions of unicellular organisms may be placed in two general classes: on the one hand are those theories which look upon the activities of unicellular organisms as determined in a manner similar to those of human beings, by a play of desires, motives, etc.; while at the other extreme are theories in which the movements are looked upon as of a character essentially similar to those taking place

[1] The above quotation from Nägeli is translated from Hertwig, *Die Zelle*, p. 66.

in a chemical reaction — the protoplasmic mass reacting rather as a substance than as an individual. Some such theory as this latter seems to be latent in the minds of many biologists; it finds typical expression in the scheme for the reactions of a unicellular organism to chemical substances given by Le Dantec (*La Matière Vivante*, pp. 50–54). In this scheme, which is illustrated by geometrical constructions and almost takes the form of a mathematical demonstration, Le Dantec assumes that there is a tension between the chemical in solution and the surface of the protoplasmic mass, and that this tension acts in lines of force directed either away from the center of the protoplasmic mass, or toward that center. The movement of the organism is then due to the difference in this tension on the two sides of the protoplasmic mass — that directed toward the center from which the chemical is diffusing, and that directed away from it. As the chemical diffuses from a center, the solution is less intense the farther one passes from the center; hence the solution is less dense on that side of the protoplasmic mass farthest away from that center. Assuming that the tension caused by the chemical acts on the protoplasmic mass in lines of force directed away from the center of the mass, it is mathematically demonstrable that this force will be stronger on the side toward the center of diffusion of the chemical, and that the resultant of all the lines of force will be a force directed exactly toward this center of diffusion. Hence the protoplasmic mass will move toward the center of diffusion of the chemical; in this way positive chemotaxis is explained. If, on the other hand, the tension acts in lines of force directed toward the center of the protoplasm, the same mathematical construction shows that the mass will move away from the center of diffusion; thus is explained negative chemotaxis.

The impossibility of reconciling the movements of the three Infusoria, whose reactions I have described, with any such theory as this is manifest. The theory, though designed expressly to explain the movements of the bacteria and flagellates used in Pfeffer's well-known experiments in chemotaxis, neglects entirely the fact of the differentiation, in those organisms, of axes along which movement takes place, as well as the fact that they move by means of definite organs of locomotion, — flagella, or cilia. To make this abstract scheme fit the concrete motions of the organs of movement would be much more difficult than to invent the scheme.

If chemotaxis acts in the direct manner supposed in such a theory as the above, the organism will of course move directly toward a source of attractive stimulus, directly away from a source of repellent stimulus, and that moreover without regard to the relation of the direction of its axes to the direction of motion. As I have shown in detail for Paramecium (*loc. cit.*), and briefly above for Spirostomum and Stentor, this is by no means true for the organisms studied. On the contrary, the direction of motion has no relation to the position of the source of stimulus, so that we cannot correctly speak of attraction or repulsion at all. The organism reacts *as an individual, not as a substance,* and the nature of the reaction is conditioned by the internal mechanism and the structural differentiations of the body of the organism. The essential distinction insisted upon by Le Dantec (*loc. cit.*) between the reactions of a unicellular organism and those of a metazoan must therefore, for these organisms at least, fall to the ground. It will not do to think of the reactions of these organisms as in any way akin to those of chemical substances.

On the other hand, the reactions are equally distant from the complexity assumed by those who attribute to unicellular organisms most of the psychological powers of higher animals. The reactions of these organisms may best be compared with the working of a machine in which the wheels are geared to turn in but one direction, whatever be the nature of the force that sets them in motion.

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February 28, 1899.