CHAPTER VIII

PROTOZOA

Definition of Animal. The word *animal* is derived from the Latin, *anima*, which literally means 'breath,' and derived from this is the idea, 'spirit,' for the *spirit* or soul is that which leaves the body with the last breath or 'spiritus.' After all, breathing movements are characteristically more distinctive of the living animals which most people observe. The complete absence of breathing movements is one of the commonest indications of death. It is probable that gradually the idea developed that breathing was associated with the ability of a living animal to move about, so that today the word 'animal' connotes *movement* rather than the more literal idea of mere *breathing*.

And yet the popular conception of 'animal' as an organism that moves about does not agree with the scientific idea since many animals, such as the corals, do not move about. On the other hand, many minute plants do move about.

Plants and Animals. It is practically impossible to absolutely differentiate between animals and plants. In addition to movement, there are other characteristics which separate most plants from animals. For example, the plant cell is usually inclosed in a cellulose box, the rigidity of which is not adapted to rapid movement from place to place. Animal cells, on the other hand, are bounded by a soft cell membrane and this property is related to the possibilities of free movements of animals. In the next place, animals possess an adjustment mechanism making possible rapid changes in position in response to sudden modifications of the environment, which affect the animal. Adjustment in plants takes place slowly. Plants do not possess the specialized organs of sensation, conduction and contraction of animals. Animals possess sensory organs and nervous and muscular systems adapted for the making of rapid adjustments. On the other hand, plants can make carbohydrate and protein compounds from inorganic ingredients.

Animals cannot do this. They are dependent upon plants for *organic* compounds from which they make their *animal* protoplasm. Plants are nearer in this sense to the inorganic world. When the botanist undertakes to make a structural analysis of the plant body, he does not find dissection to be a great help. He is forced almost at once to proceed to a microscopical study of plant tissues. The zoologist, however, finds dissection very helpful since it reveals special organs which perform special functions. After the revelations made by dissection, the zoologist then proceeds to the histological method of analysis.

And yet in spite of those distinctions which separate most plants and animals, there are many minute organisms which are considered plants by botanists and animals by zoologists. This suggests that we should not forget the fundamental resemblances between plants and animals, for the resemblances indicate the fundamental unity of organic nature. The study of different types emphasizes diversity, and we too often forget that all these multitudes of forms are merely various kinds of living *energy transformers* in which certain processes are common to all and these very processes distinguish the living from the non-living world.

Protista. One scientific view is, that life first appeared in the form of small microscopic or ultra-microscopic organisms, neither plant nor animal in the modern sense of these words. From these so-called *protista* (primitive tissue) two great lines of organisms evolved, namely plants and animals. This idea is well depicted by the letter 'Y.' The vertical portion represents the protista emerging from the inorganic. One arm of the 'Y' represents the evolution of the plants, while the other refers in the same way to the animals. As specialization in body organization succeeds generalization, the later types appear to be more and more diverse.

Animal Phyla. The animal world can be divided into a number of quite distinct groups, each with a similar body plan. These principal subdivisions are called *phyla.* Zoologists differ as to the number of phyla which indicates that classification is a human invention, necessary for any orderly presentation of animal forms.

The following list includes the principal groups or phyla of animals. (1) Protozoa (*e.g.* single-celled forms); (2) Porifera (*e.g.* sponge); (3) Coelenterates (*e.g.* coral); (4) Platyhelminthes (flat worm); (5) Nemathelminthes (round worm); (6) Annelids (earthworm); (7) Rotifera (rotifer); (8) Echinoderms (starfish); (9) Mollusca (clam); (10) Arthropoda (house fly); (11) Chordates (frog).

We shall study some of these groups in more detail than others and note a successive modification of body build from a type which is at first simple to more and more specialized plans. No one individual type is to be considered ancestral to the next higher group. For example, the Amoeba is one of the simplest of Protozoa and yet it would be incorrect to say that Amoeba is the ancestor of the higher groups. We do not know that the early ancestor was like Amoeba in all respects; but the zoologist does believe that the early forms possessed some of the characteristics of present-day simple Protozoa. No one knows what the ancestral forms of each higher phylum were. All that can be done is to conclude from comparative studies, a *few* of the *leading* characteristics of such ancestors.

There are indications of evolution within each group. The comparative morphologist decides which is the more specialized of two forms belonging to the same phylum and in general concludes that such types are less primitive than their simpler relatives.

Protozoa and Metazoa. A fundamental criterion, subdividing the animal kingdom into two groups, has to do with the number of cells constituting the animal body. We can say provisionally that *Protozoa* are single-celled animals. All the functions of life are performed by the single cell. If any physiological division of labor is present, it is accomplished by different structures within the confines of a single cell.

Metazoa are, on the other hand, animals composed of many cells. But this distinction requires further definition. Many Protozoa are organizations of more than one cell; in some cases, the protozoan body consists of hundreds of cells. They are called *colonial Protozoa.* And yet physiologically each of these many cells functions in the main as though separate from the others; each performs all the metabolic and adjustment functions of life. In the Metazoa, on the other hand, some of the many cells are organized into a special tissue or organ which has a particular function, while other groups of cells form other tissues or organs, *i.e.*, Metazoa exhibit physiological division of labor and tissue differentiation.

PHYLUM — PROTOZOA

Protozoa were discovered by a remarkable Dutch microscopist, Leeuwenhoek, who wrote: " In the year 1675, I discovered living creatures in rainwater which had stood but four days in a new earthen pot, blew within."

Protozoa are small microscopic, single-celled animals or colonies of similar cells. Many types of body form are exhibited. Some Protozoa are in many respects plant-like, while others resemble Bacteria. In the search for the microorganism causing a certain disease, investigators find it impossible to agree since some claim that it is a protozoan and others that it is a bacterium. Some Protozoa appear to be simple bits of protoplasm while others are highly differentiated. Protozoa reproduce by fission, by budding, by spores and by eggs and sperm. Protozoa occur in fresh and salt water, in damp earth, in dry dust, inside the bodies of animals and even within cells. So many things have been discovered about them that the distinct science of *Protozoology* has been established. Some protozoologists find that so many general problems of biology are presented by Protozoa, that they consider the group entitled to the rank of a separate sub-kingdom of animals. Each protozoan appears to be a distinct individual and yet some protozoologists have developed the conception that while Metazoa are animals consisting of differentiated cells, *closely associated in space* to form the body of a single organism, the single-celled protozoan, on the other hand, is only one cell of a larger organism whose component cells are *separated in space and time.* This conception results from a consideration of the unique life cycles of some Protozoa.

Protozoologists classify them into four groups:

Class I — Sarcodina: *e.g.* Amoeba

These are named from the old word for protoplasm, ' sarcode' or ' flesh.' Among these forms, the genus *Amoeba* is representative, easily obtained and widely studied. It is often referred to by writers discussing the origins of life. However, it is not the simplest of organisms, nor was it the ancestor of higher animals, though it appropriately illustrates our ideas of the nature of these hypothetical ancestors.

Morphology (Fig. 104 *A*). A living Amoeba appears to be a minute, irregular speck of protoplasm in motion. The body is composed of a soft, translucent, watery, jelly-like substance, containing a spherical nucleus, vacuoles, different kinds of granules and lifeless inclusions such as plant and animal fragments and grains of sand. The greater part of the body, containing the granules, for example, is called the endosarc or endoplasm. Surrounding this is a narrow zone of clear protoplasm bounded externally by a film, both constituting the ectosarc or ectoplasm. The Amoeba moves about by thrusting forth blunt lobes or processes of protoplasm called *pseudopodia* (false feet). One can see granules move out into these pseudopodia and back again into the body. The pseudopods are not permanent structures. While new ones form at one place, those at other points disappear as their protoplasm flows back into the main part of the body. One can also observe the formation of a *contractile vacuole*. It increases in size, eventually is located near the ectosarc, bursts and its contents are discharged to the outside.

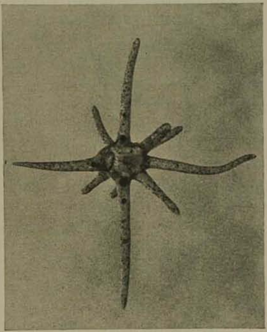

FIG. 104 *A*. — Amoeba proteus. Note the long slender pseudopodia. (Photo of model in American Museum of Natural History.) Courtesy A. M. N. H.

Physiology. Physiological activities can be divided into three groups: Metabolism, Adjustment and Reproduction.

First — Metabolism. (*a*) Ingestion of food. Amoeba feeds on microscopic plants and animals. The protoplasm of the Amoeba appears to flow around the food particle, which, with some of the water, becomes a spherical *food vacuole* in the endoplasm.

(*b*) Secretion. Appropriate enzymes from the surrounding cytoplasm mingle with the fluid of the vacuole.

(*c*) Digestion. The enzymes convert the insoluble food into simpler and more soluble compounds.

(*d*) Absorption. The digested food compounds are absorbed into the surrounding protoplasm.

(*e*) Egestion. The food vacuole has decreased in size. It now contains only undigested residues such as silica, walls of diatoms or cellulose from plant cells. Eventually, these bits come to the surface and are discharged.

(*f*) Circulation. The absorbed food compounds are distributed throughout the body of the animal by the moving protoplasm.

(*g*) Assimilation. The absorbed food compounds together with water and salts are transformed into new protoplasm.

(*h*) Respiration. Assimilation and other activities involve expenditure of energy. The release of energy in protoplasmic activities requires the presence of oxygen. Respiration refers to that process whereby oxygen from the air is brought to the seat of oxidative processes and also the elimination of CO_2. Oxygen is in solution in the water which Amoeba takes in with its food. Oxygen is also probably absorbed through the surface of the body and circulated as food is circulated.

(*i*) Oxidation. Oxidation occurs whenever and wherever energy phenomena are manifested, such as the movements of adjustment and processes of metabolism and reproduction. Energy is thus made available for living processes. Physiological oxidations at moderate or low temperatures are like oxidations of organic compounds when heated to high temperatures.

(*j*) Excretion. As a result of oxidations, protoplasm disintegrates into simpler compounds. Not only protein but carbohydrate and fat may be thus oxidized. The by-products are of no further use to the organism, and indeed of positive detriment if retained, and are therefore discharged, *i.e.*, *excreted.* Chief among these by-products are nitrogenous compounds such as urea, $(NH_2)_2CO$, water and carbon dioxide. Some investigators appear to have demonstrated that the contractile vacuole collects these products of *katabolism,* which term applies to all the destructive stages of metabolism. *Anabolism,* its companion term, refers to constructive phases of metabolism. Some Protozoa do not possess contractile vacuoles and yet must excrete. Cells of metazoan animals have no contractile vacuoles and discharge wastes directly through the cell membrane. However, this argument does not disprove the excretory function of the contractile vacuole of Amoeba, while the demonstration, by microchemical methods of nitrogenous wastes within the vacuole, largely confirms its function as an organ of excretion. It is also a regulator of water content.

All the *processes* noted above occur in the metabolism of Metazoans.

Second — Adjustment. Observers of the movements of Amoeba marvel at this phenomenon. Those who have studied it conclude that Amoeba is not aimlessly moving about but that it exhibits a definite orderly adjustment to varying external conditions. It has no sense organs, yet is sensitive to appropriate stimuli, as, for example, sudden contact with some object; it possesses no nerves, yet the change aroused by the stimulus is effectively communicated throughout the body; it possesses no muscles, yet can move from place to place in an adequate manner. Let us examine the mechanism of movement alone. This has intrigued the interest of many investigators and yet no single explanation is satisfactory to all observers. One idea is that it rolls along in much the same manner as a "caterpillar" tractor. But such a machine puts fôrth no pseudopodia and appears simple, compared with the Amoeba. Another idea is that the Amoeba walks on its pseudopodia.[1] Amoeba is positively attracted to the substratum on which it 'crawls'; it is positively attracted to food particles but sometimes takes in grains of sand. It moves away from apparently injurious chemical stimuli. Some have concluded from such observations that the behavior of Amoeba is a series of tropisms, *i.e.*, direct mechanical responses to stimuli. But its behavior at times is more complex than this. For example it exhibits a certain degree of selection when ingesting. Jennings was so impressed by the performance of this animal that he went so far as to say that "if Amoeba were so large as to come within our everyday ken, I believe, beyond question, that we should find similar attribution to it of certain states of consciousness."

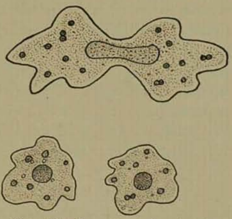

Fig. 104 *B.* — Reproduction in Amoeba.

Third — Reproduction. A single Amoeba has been observed to divide (Fig. 104 *B*), forming two small Amoebas which grow to adult size and divide again. After a number of divisions of this

[1] Amoeboid-like change of form induced by changes in surface tension may be observed in certain chemical mixtures, *e.g.* — cover a drop of mercury in a watch glass with a 2% solution of nitric acid. Place a small crystal of potassium dichromate near the mercury.

sort, individuals undergo encystment and sporulation, a process which is imperfectly understood. Apparently small spore-like forms emerge which develop into the larger form. Then follows a period of reproduction by fission. In other words, a cycle is present with life phases comparable to those of a higher organism.

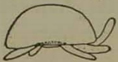

FIG. 105.—Arcella.

Sarcodina in General. Sarcodina include various forms. *Arcella* (Fig. 105) has a dome-shaped brown shell which it secretes, and its pseudopodia extend out through a circular opening on the flat surface of the shell. *Difflugia* (Fig. 106) has a more elongated, somewhat ovoid-shaped shell made of particles of sand. Both forms can withdraw into the shell. *Actinophrys* (Fig. 107) is a tiny, vacuolated, spherical mass of protoplasm with long pointed pseudopodia, each supported by a central axial filament. *Radiolaria* (Fig. 108) are marine forms, some with radiating pseudopodia and a porous, chitinous shell dividing inner protoplasm from outer. Some have a lattice-like skeleton of silica of varying patterns. The *Foraminifera* (Fig. 109) have a network of pseudopods around the entire animal or part of it. Many have a calcareous shell. The skeletons or shells of these dead Protozoa sink to the bottom of the sea, forming great deposits many of which have later been lifted up to form sedimentary rock, which may be found far above and far away from the ocean. The chalk cliffs of England, many feet in thickness, are the compressed skeletons of innumerable Foraminifera, once

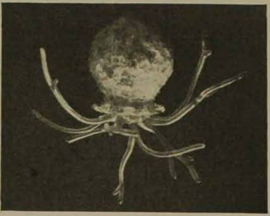

FIG. 106.—Photo of model of Difflugia. (Courtesy of American Museum of Natural History.)

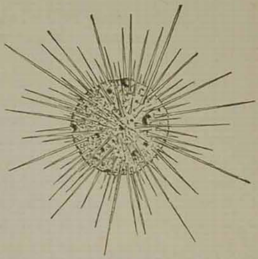

FIG. 107.—Actinophrys. From Conn: *Fresh Water Protozoa of Connecticut*. Connecticut Geological and Natural History Survey.

living animals of the sea. Nummulistic limestone, of which the great blocks forming the Pyramids are composed, is foraminiferal in origin.

Amoebic or tropical dysentery is caused by a Sarcodina-like parasite introduced by way of the mouth with water, milk or other articles of food. The specific organism is called *Entameba histolytica*. *Entameba coli* is a frequent inhabitant of the human digestive tract. Other types appear in the feces of many animals, including man.

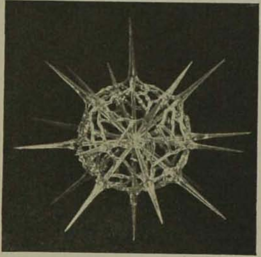

FIG. 108. — Photo of model of skeleton of a Radiolarian. (Courtesy American Museum of Natural History.)

Class II — Mastigophora or Flagellates

These are forms in which the motor mechanism consists of one or more elongated whip-like processes called flagella. They may be divided into two groups: (*a*) animal-like and (*b*) plant-like types. In many respects they are more primitive than the Sarcodina because the same individual may exhibit metabolic peculiarities of both plants and animals.

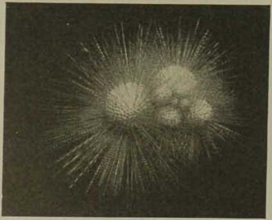

FIG. 109. — Globigerina bulloides, a Foraminifer. (From photo, Courtesy American Museum of Natural History.)

Euglena. Euglena is an example of this class. The form of the body is definite (Fig. 110). It is somewhat elongated, pointed at one end and rounded at the other. From the latter projects the long vibratile *flagellum* which arises from a slit called the mouth. The flagellum acts as a propeller in front of the animal, and drags the animal behind it. The mouth leads into a short 'gullet.' Contractile vacuoles discharge into a reservoir which in turn discharges into the 'gullet.' Nearby is a small mass of red pigment called the eye or *stigma* because it is thought to be especially sensitive to light. There is one nucleus, and there are many green chlorophyll-containing bodies in the cytoplasm. Utilizing the energy of the sun, the chlorophyll can manufacture a carbohydrate substance, *paramylum,* from carbon dioxide and water. Euglena may also ingest microorganisms like bacteria, and digest them in food vacuoles. Some types may live at times on decaying organic matter. Some Euglenas have two phases in their life cycle. In the active phase they reproduce by fission lengthwise. In the passive phase they encyst, and subdivide into many small cells, which afterwards are released, form flagella, and resume the active phase again. In many Mastigophora, conjugation, similar to that occurring in the Alga, Ulothrix, has been observed.

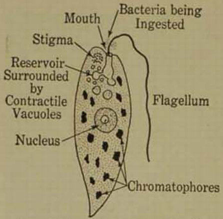

FIG. 110. — Euglena. Modified from Curtis and Guthrie (after Tannreuther): *Text Book of General Zoology*, copyright 1927, John Wiley & Sons, Inc. Reprinted by permission.

Synura (Fig. 111) is a colonial, plant-like flagellate which is often responsible for offensive odors and tastes in water supplies. The organism forms fats or oils and it is these which impart the disagreeable qualities to the water. Some flagellates contain chromatophores of one color or another. For example, areas on the surface of the ocean may be orange in color, due to the flagellate form *Noctiluca,*

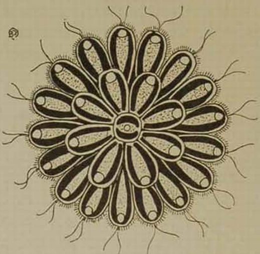

FIG. 111. — Synura. From Conn: *Fresh Water Protozoa of Connecticut.* Courtesy Conn. Geological and Natural History Survey.

FIG. 112. — Trypanasome. From Hegner (after Calkins College Zoology. Macmillan Co. Reprinted by permission.)

or colored red with vast numbers of *Peridinium.* Phosphorescence in the sea is due in part to the rapid oxidation of small particles of oil produced by Noctiluca. African sleeping sickness is caused by

Trypanosoma gambiense (Fig. 112). This flagellate is parasitic in the digestive tract of the Tsetse fly (Fig. 113), a blood-sucking insect. If an infected fly bites a person, it may introduce these parasites into the blood stream of the human victim, where it multiplies. Other Trypanosomes are harmless parasites in the blood of the frog and rat.

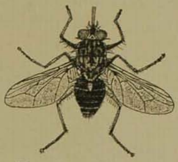

FIG. 113. — Tsetse Fly. (From drawing by Howard, U. S. D. A.)

Certain colonial flagellates are of theoretical interest. Two are here described.

Pandorina (Fig. 114). It consists of a spherical colony of sixteen cells, each provided with two flagella and surrounded or inclosed in a thin case. When the colony is mature, each cell divides four times to form sixteen cells each, *i.e.*, a small colony. These sixteen colonies break through the case, and each develops into a new colony.

Volvox (Fig. 115). This is a spherical, colonial form. The outer wall of the sphere is one layer of similar cells, thousands in number, each provided with two flagella. The interior of the sphere is filled with fluid. Each of the cells performs all the functions of metabolism and adjustment. There is no differentiation into organs. However, reproduction is effected by special cells and is asexual or sexual. In *asexual reproduction*, certain cells derived from the body wall cells, *i.e.*, somatic cells, multiply into small spherical colonies within the sphere. Later they are freed from the mother colony and become mature colonies. In *sexual reproduction*, certain cells just inside the colony wall become greatly enlarged, due to storage of nutriment in them, and form eggs. Other cells, derived also from the body wall cells and also located just within the body wall, divide and subdivide, forming small bi-flagellated, free-swimming sperm cells. Some species of this genus are *monoecious* and some *dioecious*. *Sexual reproduction is established therefore in the so-called lowest phylum of animals.* Many other Protozoa have a sexual as well as

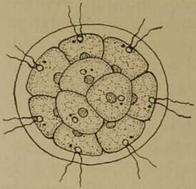

FIG. 114. — Pandorina. From Curtis and Guthrie (after Oltmann): *Text Book of General Zoology*, copyright 1927, John Wiley & Sons, reprinted by permission.

an asexual phase in their life cycle. Pandorina and Volvox are mentioned here because the development of many higher animals, belonging to different groups, exhibits embryonic stages which resemble those of Pandorina and Volvox. Furthermore, continuing this thought, biologists are wont to regard the fertilized egg of higher forms as homologous with single-celled Protozoa. Botanists include Pandorina and Volvox with the Algae. Although Volvox consists of many cells, yet there is present an integration of activities. The organism is the biological unit.

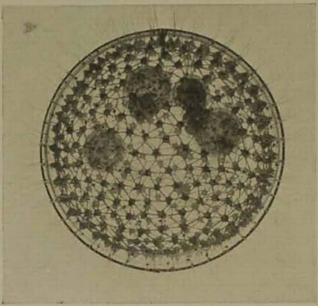

Fig. 115. — Volvox. Photo of model. (Courtesy American Museum of Natural History.)

Class III — Infusoria or Ciliates

In this class the organs of locomotion are cilia which many Infusoria possess during all phases of the life cycle while some types have cilia only in the early stage of development. One of the commonest forms is the genus Paramoecium, found in decaying *infusions* of such material as hay or other organic matter. It is easily kept in laboratory cultures.

Morphology. Paramoecium (Fig. 116) is called the 'slipper animalcule' because its outline is similar to that of a slipper with pointed toe and rounded heel. The blunt end is regarded as anterior. On one side, at this end, is the *oral groove* which extends obliquely back to about the middle of the animal. At the posterior end of this groove is the mouth, opening into a short, blind *gullet*. In the gullet is an *undulating membrane* formed by a fusion of cilia into a band which in motion directs water, containing food, into the body. Granular endoplasm and hyaline ectoplasm are present. A thin, firm cuticle forms the outer limiting membrane, preserving the definite body shape. The surface is covered with regularly arranged cilia. Just within the cuticle is a narrow, striated zone containing defense bodies called *trichocysts*.

Near the middle is a large *vegetative meganucleus* and a small *reproductive micronucleus* near it. Two *contractile vacuoles* are present, one near each end of the animal. Many *food vacuoles* are present. Behind the oral groove at the posterior end is the *anal spot*, from which undigested food matters are discharged. It is evident that Paramoecium is more highly organized than Amoeba. It illustrates the high degree of specialization characteristic of many single-celled forms.

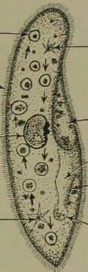

Fig. 116. — Paramoecium. Modified from Conn: *Fresh Water Protozoa of Connecticut.* Courtesy Conn. Geological and Natural History Survey.

Physiology. *Locomotion.* In moving about, Paramoecium takes a spiral course, at the same time turning on its longitudinal axis. The forward and rotating movements are brought about by whip-like lashing of the cilia backward and to the left. The spiral course is also explained by the fact that the cilia of the oral groove beat stronger than other cilia, and so tend to swing the front end of the body out of the straightforward direction. Paramoecium glides quickly into the field of microvision and out again, making careful observation difficult until it is quiet.

Feeding. The peculiar method of progression enables it to explore a wider field when in search of food. When it finds a spot rich in bacteria, for example, it becomes quiet. The cilia of the oral groove sweep quantities of food-laden water into the mouth, forming a pocket at the blind end of the gullet. Presently this 'food pocket' breaks into the protoplasm and is called a *food vacuole,* which moves toward the rear in the endoplasm. Others form and follow, one after the other. From the rear, they move toward the anterior end, then turn again toward the rear. During this *circulation* of food vacuoles, digestion takes place; digested products are diffused and the undigested residues are voided at the anal spot.

Action of Vacuoles. The radiating canals of the vacuoles extend out into the neighboring cytoplasm. Much water is taken in with the food. This collects in the radiating or drainage canals which discharge it into the central reservoirs and these when full empty their contents out through the cuticle. The vacuoles function alternately and with a certain rhythm. They probably maintain a water equilibrium and at the same time remove excretions. Other processes of metabolism are similar to those of Amoeba.

Behavior. A few years ago some biologists were inclined to view the movements of forms like Paramoecium as manifestations of a simple mechanism and from experiments with it and other organisms developed the theory of Tropisms. In moving about, Paramoecium may approach an unfavorable medium such as a drop of salt solution. It exhibits indications of being stimulated by it. Then it backs away, turns to one side, the front of the body describing an arc, and glides forward again on a spiral course. If it again comes within the unfavorable zone, it again reverses, turns in a different direction and moves forward once more. It repeats these movements until it finds a course on which it proceeds. This is called the *avoiding reaction.* It is a system of trial and error and by this method the organism finds the optimum environment as to food, temperature, light and other stimili. Although Paramoecium has no sense organs, yet it is sensitive; we know that impulses are transmitted within the body and Rees by special methods claims he has found special fibers which transmit such impulses. Such fibrils have been found in other forms. These fibers may be homologous with delicate fibrils in the nerve fibers of Metazoa.

Trichocysts are sticky, thread-like bodies, which are discharged in reactions of defense, when, for example, a Paramoecium is attacked by some other protozoan.

Reproduction. Paramoecium reproduces by binary *fission.* The animal divides transversely, forming two daughter cells. Each becomes complete in all its parts and each grows to adult size, and divides again. From *one* to *four* divisions *may* take place in twenty-four hours. If the rate is four divisions per day, by the end of the first day a single Paramoecium of this kind would be represented by sixteen descendants; if all lived, at the end of two days by 256 animals and at the end of three days by 4096 and so on. Many die, however; otherwise the world would soon be occupied by a mass of Paramoecia. At times, two individuals *conjugate* (Fig. 117), *i.e.*, come together and remain in contact for some time. During this period, the meganuclei disintegrate, while the micronuclei undergo a series of divisions and some of the resulting micronuclei disintegrate also. But finally a micronuclear body from each animal *passes over* into the *other cell* and fuses with a micronuclear body *still remaining* in the other conjugant. The animals separate. A new nuclear outfit is reorganized in each. Other nuclear changes occur before they again reproduce by binary fission. This phenomenon is restricted to the Infusoria but is not characteristic of all of them. Maupas claimed that conjugation must occur every so often, as a rejuvenating process. Woodruff, however, has kept P. aurelia without conjugation (*i.e.*, reproducing regularly by fission) since 1907. In this period he has handled thousands of generations. He has, however, supplied them with suitable food and other environmental conditions which would not be present in a state of nature. Under more natural conditions they do conjugate after many fission generations. When they are about to conjugate, a single individual, if isolated and prevented from conjugating, undergoes a complicated process of nuclear reorganization, somewhat like that in conjugation, after which it divides by fission. This process is called *endomixis*. Conjugations in certain Sarcodina and Mastigophora are of the usual type, that is, one cell formed by the fusion of two. This is a real union of gametes to form a zygote. In Paramoecium, the conjugants separate. In P. calkinsi, Spencer found that neither conjugation nor endomixis seemed necessary. Conjugation seems to have a rejuvenating effect under some conditions among certain types. It is similar to fertilization in that it affords an opportunity for the combination of two protoplasmic strains, thus giving a *chance* for

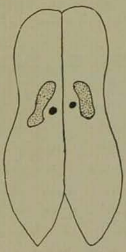

FIG. 117. — Conjugation in Paramoecium.

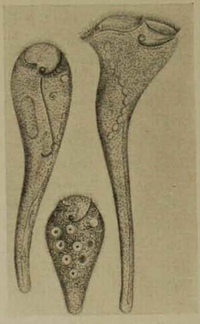

FIG. 118. — Stentor polymorphus, Müller. Courtesy American Museum of Natural History.

new types of individuals more fitted for an environmental condition unsuited to the continued existence of the forms before conjugation.

Infusoria in General. There are many forms of Infusoria. *Stentor* (Fig. 118) is trumpet-shaped when attached and at rest. The nucleus is sometimes long and bead-like. *Vorticella* (Fig. 119) has a bell-like body attached to a long stalk, the lower end of which is attached. The stalk contains a contractile thread which quickly coils up when the bell is stimulated. The animal retracts and extends in various directions searching for food organisms. *Stylonichia* (Fig. 120) has not only fine cilia, but a few larger and stiffer processes by means of which it moves or creeps along.

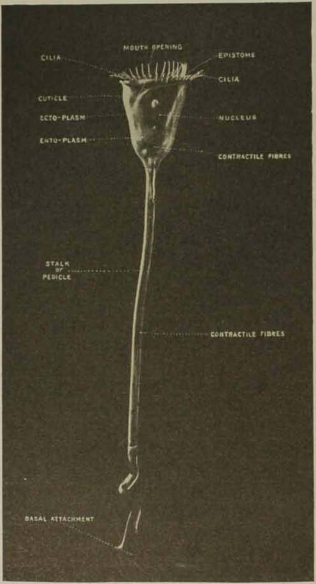

Fig. 119. — Vorticella. Photo of model. Courtesy American Museum of Natural History.

A comparison of the morphology of two forms like Amoeba and Paramoecium indicates that evolution has occurred within the Protozoan group. The highly differentiated Paramoecium exhibits within the confines of its single cell structures which may be considered organs. It is reasonable to conclude that forms like Paramoecium have traveled a long way from the primitive Protozoa — the first emergent forms of animal life.

Although consisting of but a single cell, yet observation of the behavior of Protozoa impresses one with the fact that they are independent living beings possessing individuality. One looks down through the microscope to a world on the other side of the "looking glass" — a world occupied by wonderful creatures busily occupied with activities which we interpret as being very important to them.

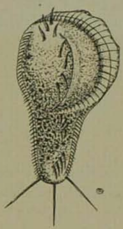

FIG. 120. — Stylonichia. From Conn: *Fresh Water Protozoa of Connecticut*. Courtesy Conn. Geological and Natural History Survey.

Class IV — Sporozoa

The Sporozoa (Fig. 121) are parasitic and many have no organs of locomotion. As the name indicates, the formation of spores is a distinct phase in their life history. One species, Porospora gigantea, often found in the gut of the lobster, may grow to be 16 mm. long. Some Sporozoa are parasitic within the body cavity of animals, some in the intestinal tract, some within the cytoplasm of a tissue cell and some are even intranuclear. They have a destructive effect upon cells. Manson, in 1907, stated that "The pathogenic Protozoa are responsible probably for a very large number of diseases." Sporozoa are transmitted to man chiefly by contact with objects containing them; as, for example, eating food contaminated with their spores. Again, an animal may be infected by some other intermediate host. Malaria is caused by a Sporozoan. For a long time it was thought that it was caused by breathing in the damp air from swampy regions. Varro about twenty centuries ago suggested the relation between malaria and the mosquito. A long series of investigations during the last quarter of the nineteenth century by many workers has corroborated this ancient supposition. The causative agent is a sporozoan belonging to the genus Plasmodium. Different malarias are caused by different specific organisms. The intermediate host is the mosquito belonging to the genus Anopheles. Of about fifty known species of Anopheles, about sixteen are malarial carriers.

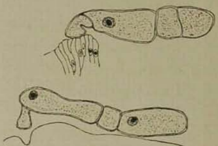

FIG. 121. — Gregarina — from intestine of meal worm, *i.e.*, the larva of Tenebrio beetle.

However, the presence of such mosquitoes in a region does not necessarily make the district malarial. In addition to the mosquitoes there must be persons who are carriers of the Plasmodium or who are suffering from the disease. The parasite is transmitted by female Anopheles (Fig. 122), since they are blood-sucking while the males feed on plant material. In withdrawing blood from the victim, the mosquito injects saliva containing a substance which prevents coagulation of the blood. If the mosquito is carrying Plasmodium sporozoites (motile spores) (Fig. 123), these are injected into the human blood stream during this process. The introduced parasites at once invade the red blood cells. There they reproduce by sporulation, and in due time a great many small spores escape from the corpuscle, which is thus destroyed. At the same time waste products including toxins are introduced into the blood stream. The liberated spores at once enter other corpuscles, later sporulate there and still later discharge many more Plasmodia spores and toxins into the blood. This process may increase to such an extent that the patient has chills and fever, becoming more severe as each new and larger crop of spores is discharged. The rapidly increasing destruction of the red blood cells is also a serious menace. After a period of reproduction by sporulation, the Plasmodia develop into male and female gametocytes. If a female Anopheles sucks blood (Fig. 124) at such a stage, these cells become gametes in the stomach of the mosquito. The gametes unite, forming zygotes which migrate through the wall of the stomach and encyst on its outer surface. Many cysts form on the wall of the stomach. Later, sporozoites emerge from the cysts and make their way into

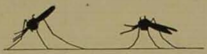

FIG. 122. — Anopheles mosquito on the left; Culex on the right. Courtesy American Museum of Natural History.

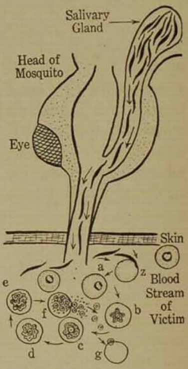

FIG. 123. — Anopheles mosquito injecting sporozoites of malarial organism into blood stream and development of the sporozoite within corpuscles. At z, a sporozoite is entering a corpuscle; stages a, b, c, d, e, f follow. Many spores escaping at f; one entering another corpuscle at g.

the salivary glands, from whence they may be discharged into a human victim when attacked by such a mosquito. Quinine sulfate given to malarial sufferers kills the parasites in most cases. However the surer method of ridding a country of malaria is to rid it of mosquitoes. That this can be done successfully was shown when the yellow-fever and malarial-infested Panama Canal Zone was turned into a model health resort. Waite writes: "Of all the insect-borne diseases malaria is the most important. It has been estimated that directly or indirectly it is responsible for more than half of the deaths of the human race. There are probably more than a million cases of malarial fever every year in the Southern States alone." And yet prophylactic measures resulting in the reduction or elimination of the mosquito and the isolation of the malarial patient has brought about the practical disappearance of this disease from many districts. Many persons of the younger generation in certain parts of the country know little about it and many of the

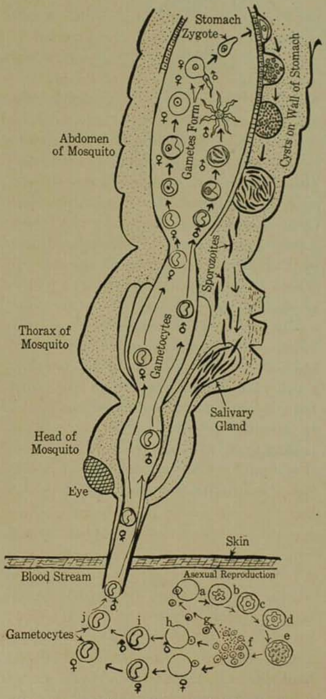

FIG. 124. — Life cycle of malarial parasite in blood stream and in body of Anopheles mosquito. Adapted from Schaudinn *et al.*

younger physicians have little professional experience with it. This is an index of the value of scientific research, for by it thousands of lives have been saved and many thousands of dollars.

It is very difficult to determine whether *certain* parasitic forms are Protozoa or Bacteria. Doubtful microorganisms of this nature appear to be the cause of many diseases. For example, some investigators claim that the organism causing Syphilis is a protozoan, a parasitic flagellate, Treponema pallidum. Others classify it with the Protophyta. The Spirochaeta of Relapsing Fever are claimed as Protozoa by some and Bacteria by others.

Texas fever of cattle is caused by a protozoan, Babesia bigemina, which lives in an intermediate host, the cattle tick (Fig. 219), Boophilus. The percentage of deaths among cattle is high. The disease spreads as follows: The female tick fills her body with blood sucked from an infested animal. The distended tick drops to the ground. Even eggs, formed by this tick, are infected. Fertilized infected eggs are deposited on the ground, develop into young infected ticks which crawl up on grass and so are able to find a passing animal, which may be thus infected for the first time.

The infection of eggs while still within the infected body of a female was first shown by Pasteur about 1865 in his classic researches on the diseases of silk worms. Pasteur discovered that moths, larvae and eggs of the silk worm were infected with a protozoan parasite, Nosema bombysis. Moreover, the larva could be infected by eating infected mulberry leaves. Only by establishing new broods, from uninfected moths feeding on protozoan-free food, could he eradicate the disease which had threatened with destruction the silk industry of France.

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