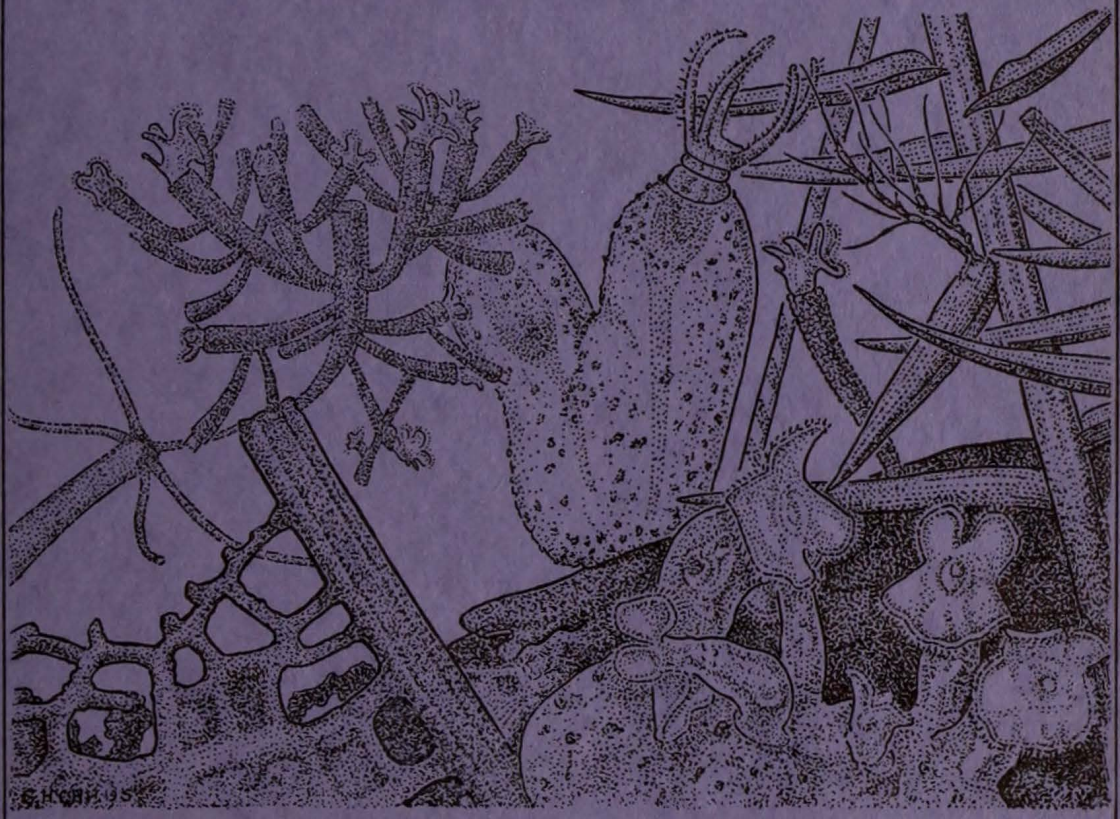
DRAMA OF THE MICROSCOPE

by

ROY WALDO MINER
Curator of Lower Invertebrates



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THE NEW ROTIFER GROUP

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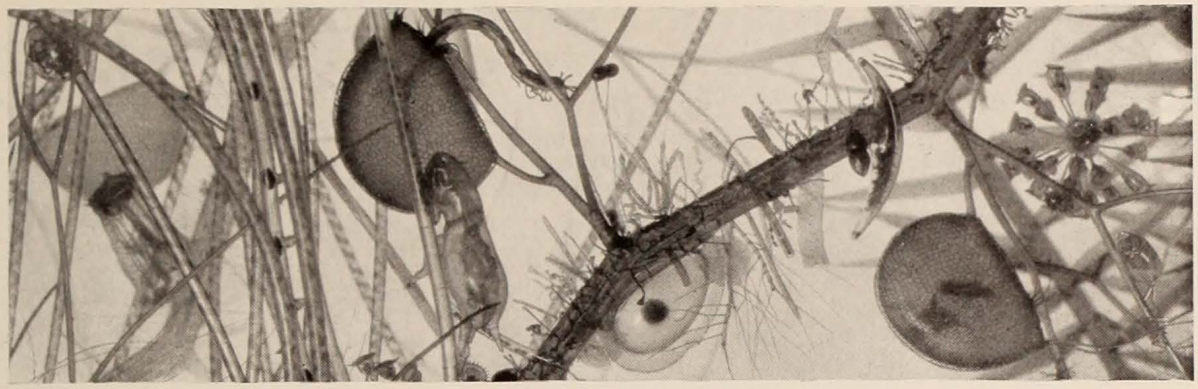
AN ENCHANTED FOREST OF THE MICROSCOPIC WORLD

A detail of the new Rotifer Group in the Darwin Hall of the American Museum, constructed entirely of glass, and faithfully portraying many of the strange plants and animals that normally might be found in one half inch of pond bottom, magnified to more than four feet in diameter



A DRAMA OF THE MICROSCOPE

The Microscopic Life Found in One-Half Inch Pond-Bottom Magnified One Hundred Diameters or, Cubically, One Million Times

By ROY WALDO MINER

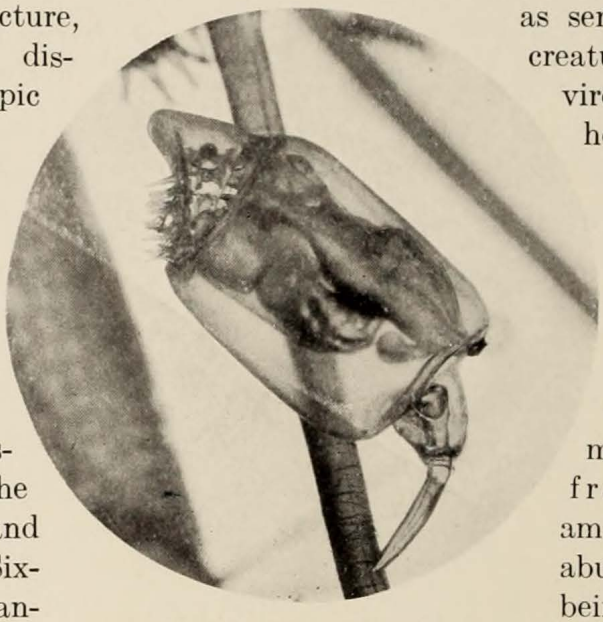
Curator of Lower Invertebrates, American Museum

The new Rotifer Group in the Darwin Hall of the American Museum was designed and directed by Doctor Miner. The field work on which it is based was largely carried on at Mt. Desert Island, Maine, by Doctor Miner in collaboration with Mr. Frank J. Myers, whose intimate knowledge of rotifer anatomy, natural history, collecting methods, and microscopic technique were of inestimable value during the preparation of the group. The field color sketches were prepared by Dr. George H. Childs, under Doctor Miner's direction. The remarkable glass modeling which is the outstanding feature of the exhibit is the work of Herman O. Mueller, of Doctor Miner's staff of artists, and sets a new mark in work of this kind, both as an achievement in skillful preparation of the hundreds of component models, and in the successful assembling into one complex whole of a multitude of fragile parts. The delicate coloring of the models and background is the work of Mr. W. H. Southwick, while those features of the pond bottom constructed in wax were modeled by Mr. Chris E. Olsen.—The Editors.

MORE than three centuries have passed since Zacharias Jansen of Middelburg, in the Netherlands, and his fellow townsman, Johannes Lippershey, produced two little instruments destined to have most far-reaching effects upon human knowledge. Both were contrivances in which crude glass lenses played a most important part. Jansen's invention was the first microscope, and was in use by 1590. Lippershey's was the telescope, which was sold by him in 1609. The following year, Galileo, in Italy, had heard of Lippershey's invention and spent a night considering the optical principles involved. By the next morning, he had reinvented the instrument for himself, and, a little later, adapted it for examining minute objects. Jansen and Lippershey were merely ingenious opticians. Galileo's adaptation of the telescope to astronomical purposes and the remarkable discoveries he made with it have coupled the instrument inseparably with his name, so that he is commonly credited with its invention, and, according to an enthusiastic biographer, with that of the microscope, as well. While all credit is due, therefore, to the two Dutch opticians for originating the telescope and the microscope, it was the genius of Galileo that perceived the significance of the former instrument and by its aid he overthrew for all time the ancient Ptolemaic cosmogony, assiduously fostered by the ecclesiastics of the day, and demonstrated the truth of the essentials of the Copernician theory. From that time on, to all intelligent men, the earth moved around the sun. The world now knew that Jupiter had satellites, that the strange planet, Saturn, existed, that there were spots upn the face of the sun, the observation of which proved its rotation.

While the microscope was not at first used for the study of natural history, by the middle of the Seventeenth Century, a group of keen observers, including Hooke and Grew in England, Malpighi in Italy, and Swammerdam and Leeuwenhoek in Holland, turned its magnifying power upon hitherto invisible details of animal and plant structure, and the last-named discovered the microscopic world of life.

Men had formerly lived in a world bounded by the limits of their unaided eyesight. That which existed beyond was the subject of more or less fantastic surmise. While the mathematicians and astronomers of the Sixteenth Century dimly anticipated something of the truths of the universe outside the range of their visual apparatus, the invention of the telescope and the microscope suddenly furnished glass windows to the practically flat and two-dimensioned room in which mankind had hitherto dwelt. Through the one they now gaze up into the starry heavens to see the planets swinging on their appointed courses around the sun. They penetrate interstellar space and comprehend that the twinkling stars are immense suns of other systems, that outside our universe are other unbelievably distant universes dimly shadowed like luminous cloud patches. Through the other window, the microscope, they gaze down into their own world of life, so enlarged by the magic of refracted light rays, that even the minute cells of animal and plant tissues are disclosed to view, as the fundamental units of living structure. In a drop of pond water, Leeuwenhoek saw myriads of minute living creatures, the existence of which was hitherto unsuspected, because invisible to man's naturally coarse vision. These living beings crowd their watery habitat, hurrying hither and thither on the business of life, as seriously intent as the creatures of our larger environment. Leeuwenhoek thus became the pioneer adventurer in this new world, which interpenetrates our own so intimately, and yet, through the accident of size, is so immeasurably separated from us. He was amazed at the variety and abundance of these tiny beings and his writings betray his confusion of mind. His letters, published from 1673 to his death in 1723, largely written to the Royal Society of London, were filled with accurate but yet miscellaneous descriptions of his observations. They were accompanied by a wealth of drawings, remarkably faithful, considering the time in which he lived and the crudity of his instruments. For his microscopes were mostly simple magnifiers, which he ground and mounted himself. He possessed 247 of these, containing 419 lenses, which apparently gave him magnifications of from 40 to more than 270 diameters. They must have been of fine quality, for the most part, judging from his results.



A SAVAGE ROTIFER

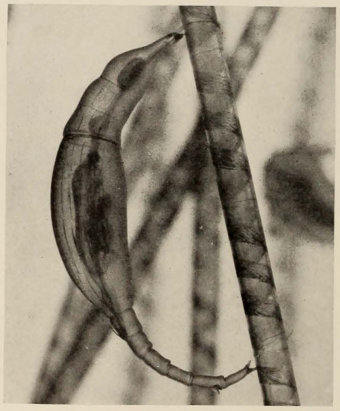
Dicranophorus crouching to spring upon its prey. Lightly balanced on its pointed toes, with body contracted, it awaits an unwary victim

Among the most conspicuous of the microscopic creatures that attracted Leeuwenhoek's attention were the animals since known as rotifers, of which he pub-

A ROTIFER JUNGLE SEEN THROUGH A MICROSCOPE

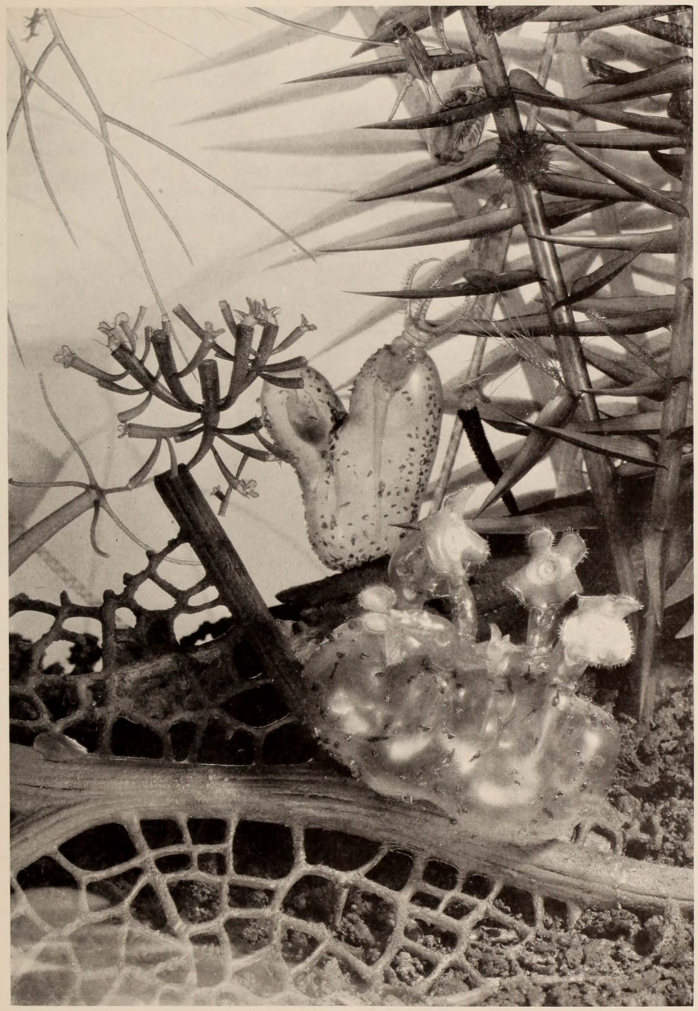
The new Rotifer Group in Darwin Hall of the American Museum, exquisitely modeled in glass, represents a cubic half inch of pond bottom magnified one hundred diameters, or, cubically, one million times. A spray of the carnivorous water plant *Utricularia vulgaris* spreads its bladder-shaped animal traps diagonally across the field of view, to snare the microscopic rotifers and other tiny creatures which make up its food

lished descriptions in 1703. A contemporary investigator, the Rev. John Harris, antedated him by seven years in making the first published, but rather vague, description of an undoubted rotifer. Thus, these remarkable inhabitants of the minute world, first recorded in 1696, have been known to microscopists for 230 years. Yet it is quite likely that by far the greater majority of educated persons today have never heard of them, and at the first mention of their name, would immediately ask "What is a rotifer anyhow?



A ROTIFER CLIMBING UP A PLANT STEM
With swimming discs folded in and concealed, *Rotaria macrura* hunts for small organisms along a *Spirogyra* stem, advancing like an "inch worm" by alternately arching and extending its body

The new exhibit in the Darwin Hall of the American Museum is intended to answer this question. Rotifers are unknown, simply because of their small size. The new Rotifer Group enlarges a cubic half-inch of their watery habitat, to one hundred diameters, or, cubically, one million times, so that it occupies a space measuring fifty inches, or more than four feet across. The front of the exhibit is constructed to represent a huge magnifying glass, through which the visitor peers into a jungle of water plants peopled by hundreds of tiny animal forms. In their natural size, these plants would cross and recross an area about the size of one's thumb-nail. Here, they are so greatly enlarged that they appear to tower above the observer's head, and their great size gives them a strange and unfamiliar appearance. These and all the other remarkable and complex features of this group have been skillfully modeled in glass to represent the life of a minute area exactly as it appears through a microscope. To the right, a cluster of water thyme (*Philotria canadensis*) rises with slender, pointed leaves and graceful translucent green stems. To the left, and arching also over from the right, criss-cross tangles of *Spirogyra* interweave their slender, tubular strands. When seen in natural size, this plant appears to consist of close tangles of slender silken threads of green, which gather in great masses in still water, and is familiar to us all under the name of "pond scum." It is supposed by many people to render the water noxious. The opposite, however, is true, as the green color of the scum is due to the abundant chlorophyll, which, under the action of sunlight, breaks up the harmful carbon dioxide gas of stagnant waters, utilizing the carbon for food, and releases free oxygen, thus rendering the water purer. In the magnified representation of *Spirogyra*, shown in the group, the strands are seen to be formed of cylindrical cells set end to end, and the green chlorophyll is gathered into spiral bundles (chromatophores), giving the strands of the plant a spirally striped appearance. Hence, the name, *Spirogyra*, is quite appropriate. When two strands of *Spiro-*



FLOWER-LIKE ROTIFERS SETTLED IN A NOOK AMONG THE WATER PLANTS

A colony of tube-building rotifers (*Floscularia ringens*) has built a branching cluster of trumpet-shaped "houses" on the edge of a dead, skeletonized leaf. In the center is the transparent, double dwelling of a pair of graceful, comb-armed rotifers (*Stephanoceros fimbriatus*), which are really ingeniously contrived animal traps of voracious habit. In the foreground, the large and unusually beautiful *Octotrocha speciosa* peer out of their jelly-like habitation

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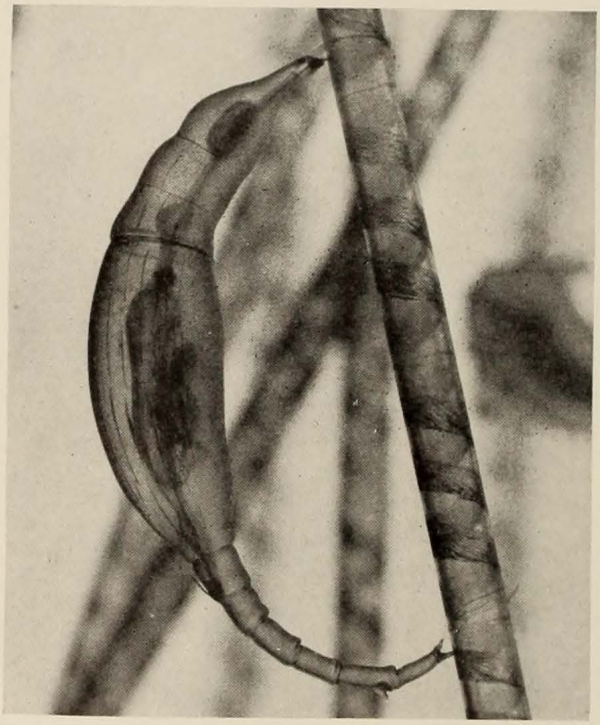

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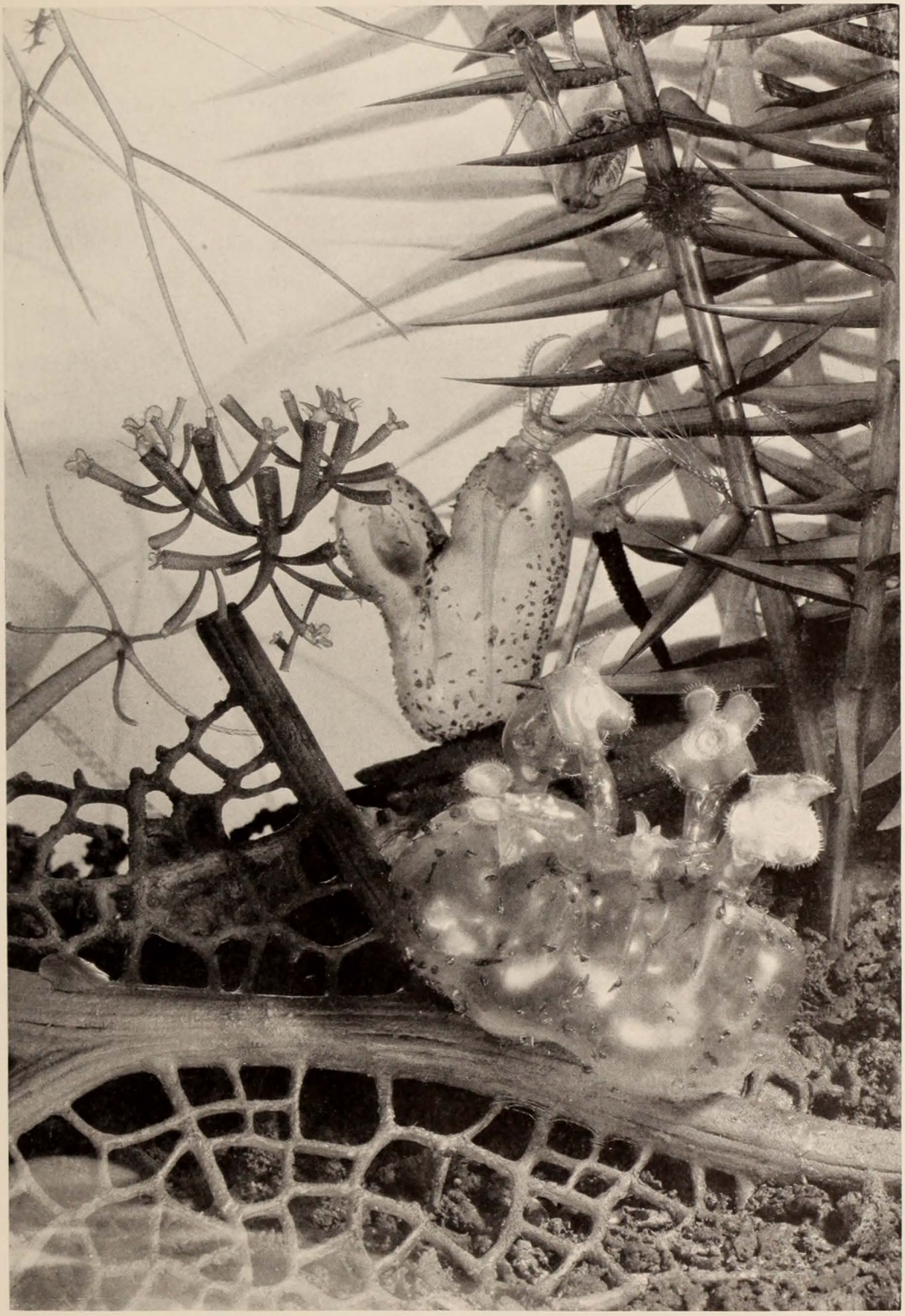

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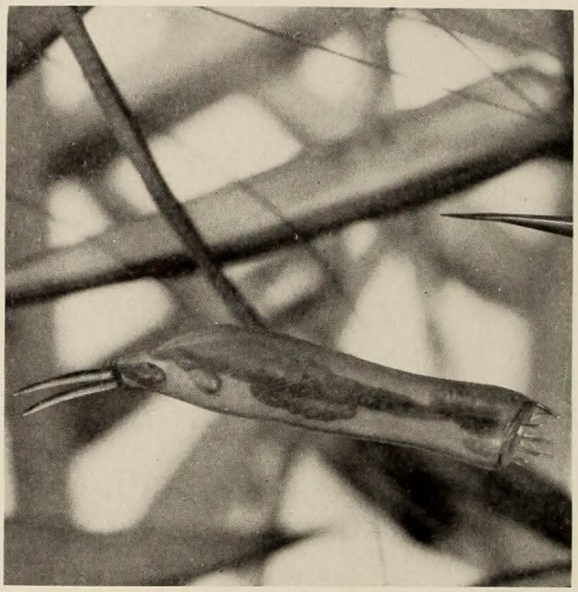
gyra come in contact, the cells which chance to be closest send out hollow projections to fuse with those of the opposite strand and connect the cells in pairs. The chromatophore of one cell of a pair thus united, then passes out of it through the connecting canal into the other cell and unites with the substance of its chromatophore, forming an oval body, which, after union of the cell nuclei, becomes a spore. This is released into the water and eventually starts the growth of a new plant.



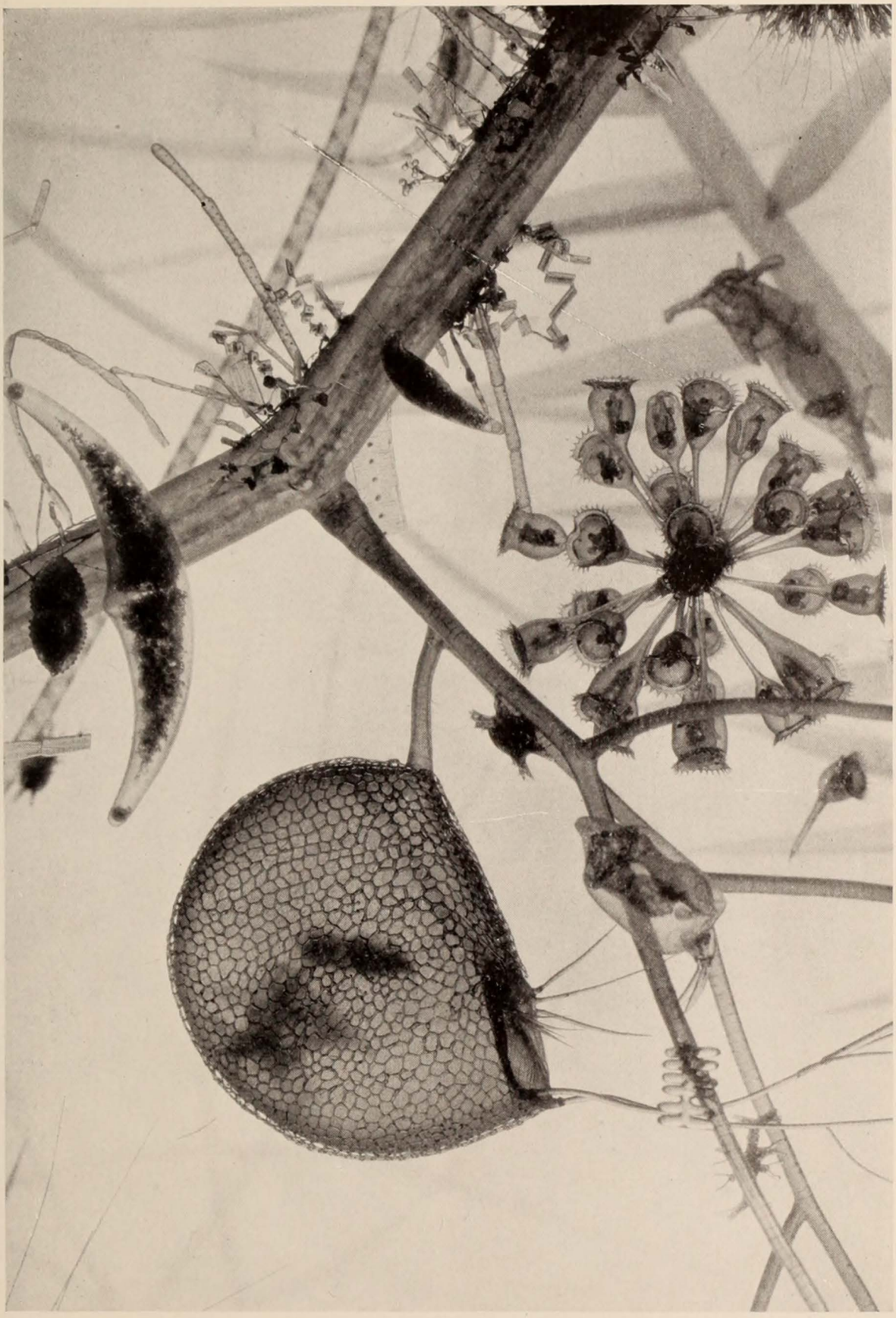
THE TIGER SPRINGS

The *Dicranophorus* darts upon its victim with open, pincer-like jaws (seen at the right), and relaxed and now slender body. This is the same species of rotifer as the one shown on page 4

Diagonally across the center of the group is seen the most remarkable plant of all. This is the bladderwort, *Utricularia vulgaris*. Its stem is slightly zigzag,and, through its translucent walls may be seen the green vascular bundles of the internal structure. Along the stem, at intervals, are slender, branching, spine-like leaves, which, in real life, are very delicate and flexible. From the stem of each of these grows a curious bladder, also called a utricle. These bladders give the name, bladderwort, to the species. From the word, utricle, is derived the scientific name, *Utricularia*. These utricles are actually animal traps. They are about the size of a pin-head, but are shown here, modelled in glass, about three or four inches in diameter. The tiny animals, with which our microscopic world is swarming, are captured by these traps and, as they die and decay, are absorbed by the plant cells for food. This reminds us of the terrestrial pitcher plants, which capture and digest insects on land. Growing upon the main stem of the bladderwort, we see hosts of minute plants, the unicellular algæ. These are of many varied species, and are so crowded together that they appear like a fine green or brown fluff when seen by the naked eye.

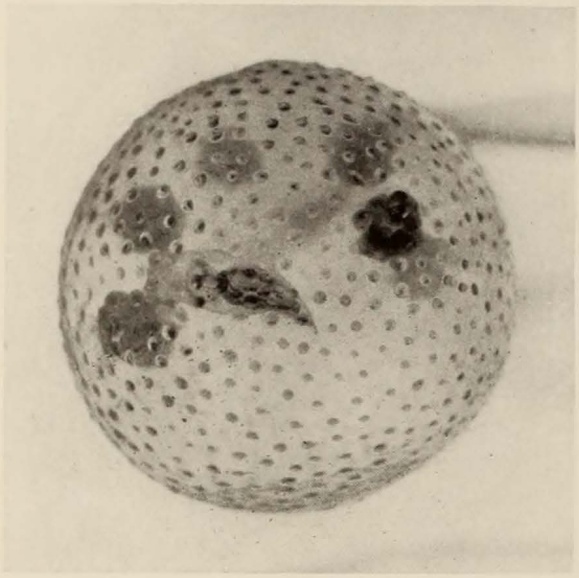
We have examined the vegetation of our microscopic jungle. Let us now become acquainted with its inhabitants, the minute creatures that swim or prowl through its tangled growths or build crystal palaces, in which they dwell upon its branches.

As above mentioned, the most conspicuous of these are the rotifers. The typical rotifer is a somewhat top-shaped animal, that is to say, its body tapers from a relatively large, often flattened head, to a more or less pointed foot, usually furnished with two, likewise pointed, "toes." An excellent description with illustrations was given in a recent number of NATURAL HISTORY by Frank J. Myers, in an article entitled "What is a Rotifer?" (May-June, 1925, page 211.) The head has a crown of cilia, i.e., minute moving hair-like structures. The arrangement of this "corona" varies in different species. In some cases, as in the common rotifer (*Rotaria macrura*), these cilia are arranged in a double row around two circular discs, which are literally borne on the shoulders of the animal, just back of the



A WATER PLANT THAT TRAPS AND DEVOURS MICROSCOPIC ANIMALS

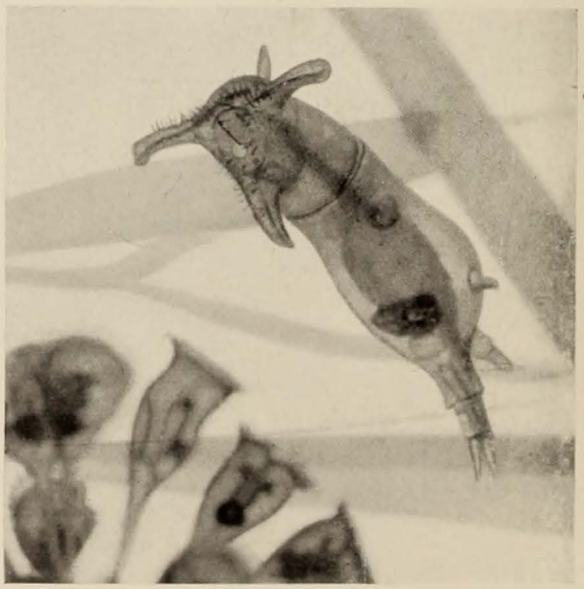
A detail of the Rotifer Group showing a single "utricle" of the bladderwort (*Utricularia vulgaris*). This, in the living plant, is about the size of the head of a pin. The trap-door is seen at its lower right margin and a captured rotifer is visible within. A spherical, floating colony of rotifers which cling together by their toes (*Conochilus hippocrepis*) is seen at the right. The stem of the bladderwort is covered with tiny fresh-water algæ, and a crescent-shaped desmid (*Closterium*) shows at the left



A ROTIFER WHICH LIVES INSIDE A COLONY OF PROTOZOA

The spherical colony of the protozoan, *Volvox*, is penetrated by the rotifer *Ascomorpha*, which thereafter lives and feeds inside

mouth-opening and on either side. The cilia lash the water, not indiscriminately, but one after the other in ordered succession. This vibrating movement is so rapid that a wave of motion passes around the discs, giving the appearance of a rotating wheel. Some of the early observers supposed that this was actually the case, and so gave the name rotifers or "wheel bearers" to the animals. They thought that, at last, the principle of the wheel had been discovered in nature, but, with closer observation, it was soon found that this was an optical illusion, and that man still preserves intact as his own invention one of the few mechanical principles not anticipated by nature, namely, that of the wheel rotating upon an independent axis. The rotifer's vibrating coronal circlet of cilia creates a whirlpool in the water, which gathers in still more minute animals, diatoms, and other microscopic particles to be swept down into the vortex where the wide-open mouth is situated. The food stream then passes into a capacious pharynx, to be seized upon by a curious apparatus, peculiar to rotifers, known as the mastax. This is really a set of jaws located in the throat, which differ characteristically in the various species, so that they are used by students of rotifers as a means of identification. In many species, they take the form of toothed forceps that tear the food apart. In others, they act as a grinding mill, and, in still others, as a suction pump. Rotifers of the first sort are active and sometimes prey upon animals of their size or larger. In this case, the rotifer springs upon its prey, suddenly shooting out nipper-like jaws until they project from its mouth, thus enabling it to seize the captive. An example of this is *Dicranophorus forcipatus* (shown on page 8). The second kind, like *Rotaria macrura*, described above, feeds upon very small forms, while those that have suction jaws are herbivorous, feeding upon the contents of plant-cells. For example, *Monommata longiseta* crawls up the filament of *Spirogyra*, cutting a neat round hole in each cell with the tips of its jaws. Then it uses its pumping apparatus to empty by suction the entire



A ROTIFER WITH STRANGE SWIMMING ORGANS

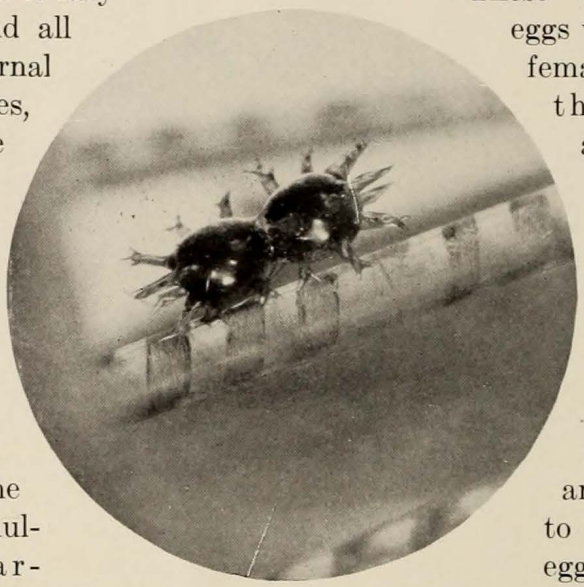
Notommata copeus extends earlike flaps from its head to use in swimming. They are fringed with moving hairs which draw the animal through the water

A PROTOZOAN COLONY OF BELL-ANIMALCULES (*VORTICELLA CAMPANULA*)

Each individual is anchored by a delicate thread of protoplasm which contracts spirally when the owner is disturbed. Highly magnified strands of pond scum (*Spirogyra*) are conspicuous, spiral chlorophyll structures showing through the transparent, tubular walls. Two strands are forming spores, being connected by ladder-like rungs in the process

plant cell of its endochrome. It then proceeds to the next cell to repeat the process.

After passing the mastax, the food reaches the large stomach, which is the most conspicuous organ in the rotifer's body. In the group, it is easy to see this organ and all the rest of the internal anatomy of each species, as the animals are clearly transparent. The stomach has a comparatively thick wall composed of a limited number of large cells which are clearly visible in the larger species and give the organ a somewhat mulberry-like appearance. Here, the food is digested, the residue passing out through the short and straight intestine. One urn-shaped species (*Asplanchnopus multiceps*) has a well-developed mouth and pharynx, as well as a large stomach, but there is no intestine present, the indigestible residue of the food being regurgitated through the mouth.



A MICROSCOPIC WATER PLANT *Xanthidium armatum* is composed of two connected cells armed with spines, which enable it to cling to plant stems

All female rotifers have an ovary situated in front of the base of the stomach. When the eggs are developing, this organ may be so distended as practically to fill the body cavity. The eggs are laid in the water in most cases. Certain species, however, hatch them in the body cavity, the young remaining for a time within the mother's body. Males are very few, compared with the number of females, and are of much smaller size. They have a reproductive apparatus, but no mouth or stomach. They are therefore merely sexual machines which swim about for a few hours before perishing. During their brief career, some of them justify their existence by pairing with the females. The rest just die. The fertilized eggs last over the winter and hatch out the following spring to give rise to females. These produce unfertilized eggs which also hatch out females. Thus, during the summer, brood after brood of females are produced, until cold weather sets in during the fall, when male-producing eggs of smaller size are hatched out, making it possible for another sexual mating to give rise to winter eggs, as before.

Rotifers have a nerve ganglion, or "brain," in the head region, in close connection with which one or more red eyespots occur. A system of nerves connects the brain with various parts of the body. They also have paired "kidneys" and a simple muscular system. In short, they are remarkably complex creatures for their small size, and are in sharp contrast to the single-celled protozoa, associated with them in their microscopic environment, which, in some cases exceed them in size.

Thirty-one species of rotifers are shown in the group. This is not unusual in a normal prosperous community found within a cubic half-inch of pond-bottom, under the environmental circumstances represented in the Rotifer Group. A few of the more interesting species will be mentioned.

One of the largest of the rotifers may be seen crawling up a *Spirogyra* filament toward the left of the group. This is

A VISTA THROUGH A TANGLE OF POND SCUM (*SPIROGYRA*)

The spiral chlorophyll of *Spirogyra* is clearly visible. A large rotifer (*Notommata copeus*) is crawling up a strand, systematically perforating it, cell by cell, to pump out the chlorophyll for food. A utricle of the bladderwort is capturing a harlequin fly larva, which is struggling to escape. At the lower left an urn rotifer (*Asplanchnopus multiceps*) is seen, with its internal structure showing plainly through its transparent body

Notommata copeus. It has the habit of perforating the *Spirogyra* cells and pumping out the endochrome, like *Monommata longiseta*, mentioned above.

At about the center of the group, another *Notommata copeus* is seen swimming. It has a pair of "ear-lappets" extending on either side of its head. These are covered with moving cilia, the rhythmic vibrations of which propel the animal through the water. When it settles on a plant stem to feed, the lappets are drawn in. Just below it is a spherical colony of beautiful rotifers (*Conochilus hippocrepis*) consisting of about twenty-five individuals clinging together by their toes, while the combined motion of their wreaths of cilia causes the whole colony to rotate through the water. Close below the latter, a savage *Dicranophorus* is crouched with its toes resting against a branch of the bladderwort, in readiness to spring upon the next unwary creature that swims by. The utricle near it has apparently forestalled the *Dicranophorus*, for, through the bladder wall, a captured rotifer is dimly seen, vainly trying to find a way out.

Farther down the spray of the bladderwort, an insect larva (that of the harlequin fly, *Chironomus plumosus*) has just been caught by a utricle, and is struggling to escape. The more it struggles, the farther in it goes, for the utricle is lined with glandular hairs pointing inward. Thus, only the muscle contractions in an inward direction are effective. Soon the creature will slip wholly within, and will coil up like its fellow in the bladder farther up the stem, finally to be absorbed by this strange carnivorous plant. How is it possible for a utricle to induce a rotifer or other unsuspecting water animal to come and be caught? By looking at the utricle depicted on page 9, it will be seen that there is a trap-door on the lower free corner of the bladder, from the edge of which project long, branched spines. Rotifers and other small creatures delight to browse among these spines, for small forms of life often adhere to them. In the course of their feeding, they may chance to come in contact with the trap-door. The shorter spines on the upper edge of the door hinder them from easily moving away, and meanwhile the slippery, glandular hairs which cover the surface of the trap cause the victim to slide toward the depression at the upper edge. Here the trap-door is very thin and flexible with a free edge gently held under a curving lip forming that part of the door-frame. As soon as the creature touches this flexible edge, it suddenly gives way and the unhappy explorer drops through the crevice, which immediately closes. The bladder does not digest the rotifer, for no digestive ferment is secreted, as in the case of terrestrial pitcher plants. The animal gradually dies, the fluid products of decay being absorbed by the cell-lining of the utricle, as food for the plant. Water-fleas and protozoa are also captured in this way.

Various species of protozoa are shown in the group. Down at the left, clinging to the base of the bladderwort stem, is a colony of beautiful bell-animalcules (*Vorticella campanula*). These are animals consisting of a single cell each. Superficially they remind one of rotifers, for the bell-shaped body is crowned by a circlet of cilia, but the internal organization is that of a protozoan, with a nucleus and contractile vacuoles. Each individual is anchored to the plant by means of a long, slender filament of protoplasm, containing a contractile thread of denser protoplasm. If the animal is touched or otherwise disturbed, the thread contracts, drawing the stem suddenly down to a close spiral, while the bell-shaped body and its ciliated disc contract into a ball. Soon the thread relaxes and the stem slowly lengthens, while the ciliated bell gradually expands and starts beating the water as merrily as ever.

A TUBE-BUILDING ROTIFER BUILDS ITS CHIMNEY-LIKE DWELLING

Floscularia ringens extends its pansy-like head from the top of its tube and models tiny, spherical bricks of brown mucus with the aid of the finger-shaped projection just back of its head. When finished, these are neatly cemented to the tube margin. The rotifer's home is thus built up like a tiny chimney of the most delicate masonry, resembling fine mosaic

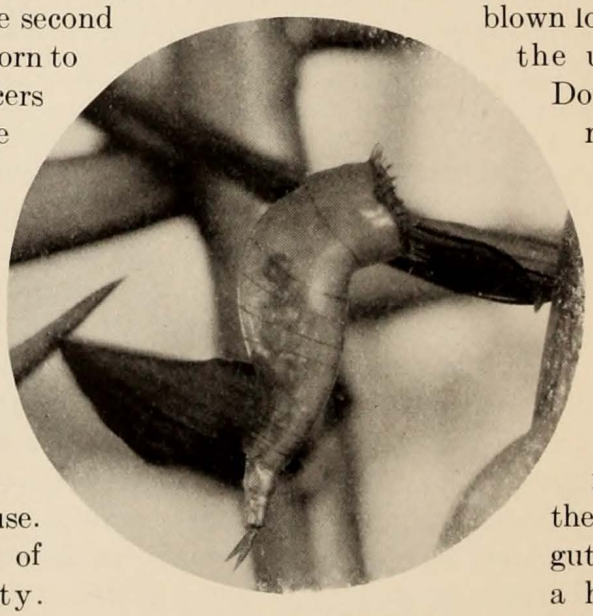
A little to the right of the center is a floating transparent ball, covered with hundreds of tiny green dots, enclosing a number of small dark green spheres. This is a protozoan colony (*Volvox*), often found in fresh water during the spring. The living colony is about half the size of a pin-head, and is very beautiful as it rotates slowly through the water. Each green dot is an individual protozoan, while the small green spheres within are developing *Volvox* embryos. Strange to say, a species of rotifer (*Ascomorpha volvocicola*) lives within the colony, and hatches its eggs there. The young grow and feed within the colony, possibly on the developing *Volvox* embryos, eventually making their escape, only to bore their way into other colonies of *Volvox*.

Perhaps the most beautiful of the rotifers are the flower-like stationary species. A good example is the tube-building rotifer, *Floscularia ringens*. The ciliary wreath of this fairy-like creature extends its petal-shaped lobes, causing it somewhat to resemble a pansy, around the rim of which the extremely delicate cilia vibrate in succession, like a transparent halo of motion. This animal builds a trumpet-shaped chimney to dwell in of tiny spherical bricks of brown mucus, secreted from glands of its body. It spins them into balls one at a time, by means of a hairy, spinning-projection upon its shoulder, and then, with a bob of its head, adds them to the upper rim of the chimney, which thus grows higher and higher. When the young are hatched, they make

their way out of the tube, and settle down on the outside of the parental mansion, to construct their own homes as additions to it. Soon, quite a branching cluster of these chimneys will be built up. Such a cluster may be seen on the edge of the dead leaf at the bottom of the group.

In the lower right-hand corner, near the branching chimneys of *Floscularia*, are magnificent clusters of two other stationary species. One of these, *Stephanoceros fimbriatus*, has built a double chimney of transparent gelatinous material, and shows one individual retired into its house, while the other extends its graceful head with five curving, fern-like arms out into the water. Fairy-like as this creature may appear, it is a most insatiable animal-trap, for its arms form a net to entangle swimming rotifers or protozoa. These settle down into a funnel-shaped vestibule from the bottom of which a hollow whip extends into a second chamber below. When the victims in the funnel touch the base of the whip, they are suddenly *snapped through its hollow lash* into the second room. Here they are torn to pieces by toothed pincers and conveyed to the stomach. So the fairy, after all, is a most voracious Gorgon!

In front of this creature, may be seen a colony of flower-like rotifers, living clustered in a roomy gelatinous house. This is a species of remarkable beauty. Its scientific name is *Octotrocha speciosa*. It was first discovered in China. Then some years ago, it was found in a pond on Long Island. Later on, Frank J. Myers discovered it abundantly in southern New Jersey, and, within the last few years, both Mr. Myers and the writer found it in ponds on Mount Desert Island. For the most part, it occurs in association with dead oak leaves, but, in the latter locality, it was abundant on the water-plant, *Nitella*. How could such a species be of such sporadic and yet wide-spread occurrence? The most probable answer is doubtless the clue to the wide distribution of many rotifers. When pools, in which rotifers occur, dry up, the animals may die or, in case of many individuals, they may go into what is known as "resting stage." The rotifer telescopes into a contracted condition, and stops, with plugs of hardened mucus, any openings through which its small modicum of moisture might evaporate. In such a state, it will resist drying up. Yet, being of the size of a mote, it is easily caught by wind currents and blown long distances through the upper atmosphere. Doubtless, millions of rotifers, as well as their winter eggs, are sown all over the world by the winds, and, when dropped in favorable localities, they dissolve out, come to life, and prosper once more. It is a fact that the dust from a dry rain gutter, on the eaves of a house, will be found prolific in bdelloid rotifers, when placed in a dish of water.



A TYPICAL ROTIFER

Cyrtonia tuba is a top-shaped creature crowned with a wheel-like wreath of cilia

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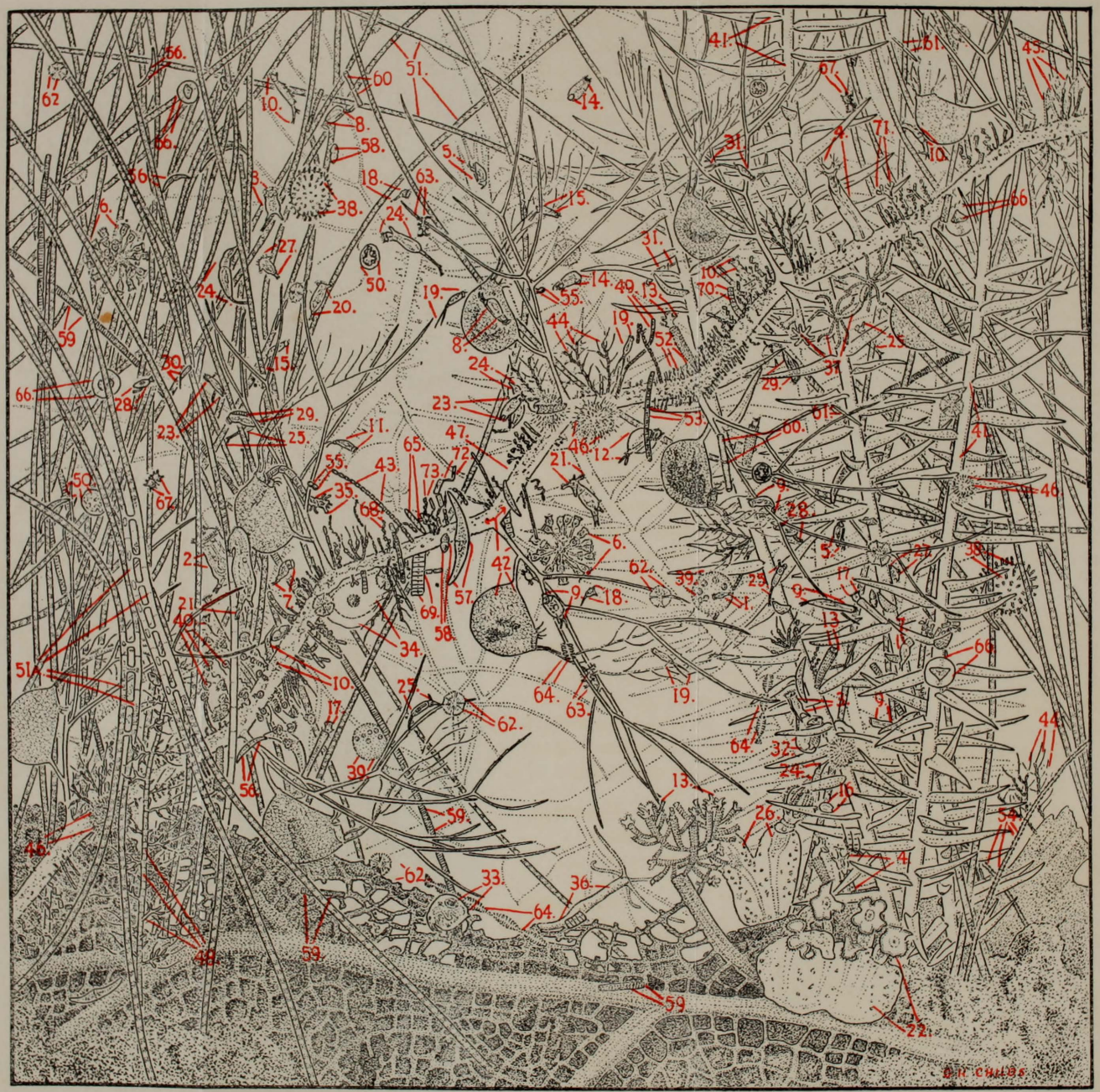

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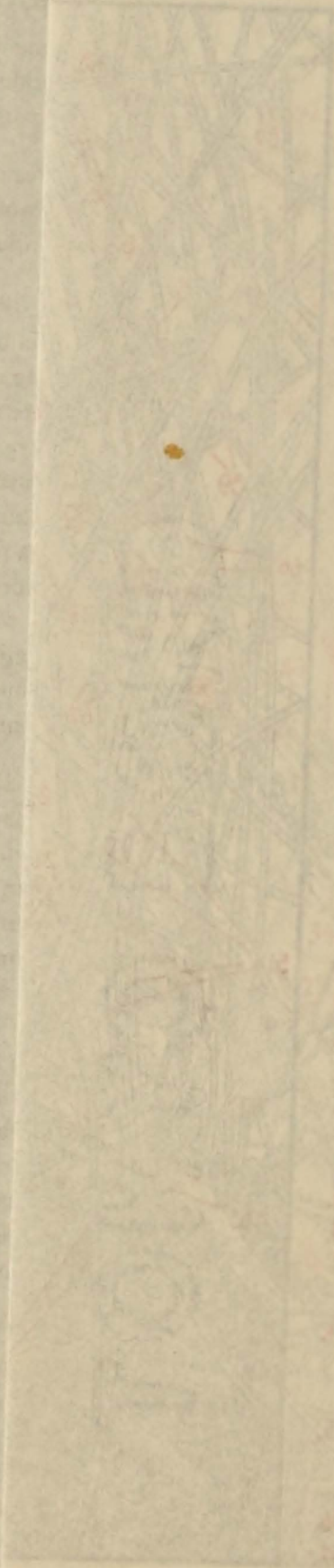

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